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ON THE RELATION OF FOOD TO THE PRODUCTION OF MILK AND BUTTER FAT BY DAIRY COWS

BY

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A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
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ON THE RELATION OF FOOD TO THE PRODUCTION OF MILK AND BUTTER FAT BY DAIRY COWS.

F. W. WOLL.

INTRODUCTION.

The branch of agricultural chemistry which deals with problems and phenomena connected with the feeding of farm animals and which is now generally referred to as the science of animal nutrition, may be said to date back to the early sixties of last century; the foundations upon which this science rests were laid by the classical investigations on the nutrition of ruminants by Henneberg and his pupil Stohmann. The accounts of these investigations were published in 1860 to 1870, in three volumes known as the Weende reports (1). The laws of the nutrition of carnivora had only shortly before been taken up for study by the Munich scientists Bischoff and Voit, whose results were published in the year 1860 in one of the classics in the literature on animal nutrition, entitled "On the Laws of the Nutrition of Carnivora" (2).

The investigations referred to form the basis of our present knowledge of the manner in which our domestic animals utilize their food, and of the importance and the office of the various food components in the feeding of animals. They represent the first continued systematic studies of this subject from a bio-chemical point of view, which were made with the invaluable aid of the Pettenkofer respiration apparatus. Naturally therefore they have been of fundamental importance in the further development of this science, and have determined to a larger extent than any other single investigation, the general character of the problems to be studied and the experimental methods to be followed in their study. Previous earnest efforts had been made, it is true, to bring the feeding of farm animals from a wholly empirical art into a definite scientific system. But this could not be done, with any success, until the application of the natural sciences, notably physiology and chemistry, had been extended to every-day affairs, and

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from man to beast. It is the undying glory of the great German agricultural chemist, Justis v. Liebig (3), that he first used the new natural sciences to elucidate problems connected with the feeding of farm animals, and that his fertile brain and enthusiasm gave the impulse to scientifically trained men, among them those mentioned above, to devote their energies to the study of feeding problems and the principles underlying the growth of farm animals and their production. With Liebig, the French chemist and farmer Boussingault (4) should be mentioned as one of the early students of animal nutrition; from 1836 on he conducted feeding experiments with milch cows at his experimental farm at Bechelbronn in Alsace, in which chemical analyses of feeding stuffs figured for the first time.

The names of two English pioneer agricultural investigators, Lawes and Gilbert (5), of Rothamsted Experiment Station, should be mentioned with Liebig and Boussingault. Their work in feeding cows and other farm animals with a view of determining the comparative value of different feeding stuffs and food components, conducted during the middle of the last century, has been of great importance, and like most results published by them, are classic contributions to the questions studied.

EARLY EFFORTS OF SYSTEMATIC FEEDING.

Hay Values. We may look upon the scheme of hay values of different feeding stuffs advocated by Thaer and other early agricultural teachers as the first effort to reduce the feeding of farm animals to a system, as regards the amounts as well as the quality of the different feeding stuffs to be fed under varying conditions. The hay values were the practical outcome of experiments and experience gained by Thaer and contemporaries, and were intended to show the value of the different feeds for feeding purposes referred to a standard unit, viz., that of good meadow hay (6). Later agricultural writers and teachers, Schwartz, Weckherlin and others, modified the Thaer hay values to some extent, without changing the system of valuation, which remained based on a supposedly fixed equivalence of definite amounts of the various feeding stuffs for the nutrition of farm animals. It was soon found, however, that the hay values did not always represent correctly the comparative value of different feeding stuffs, and as a result the values published by different authors varied considerably. As chemical analyses of the different feeding stuffs accumulated and the proximate composition of feeds became better understood, systems of valuation of feeding stuffs were based on the amounts of food components like protein, fat and carbohydrates contained in the respective feeds. From this standpoint to the next was a short step, to determine the amounts of these different components which the various animals required for their daily sustenance, for the production of an increase in body weight or of animal products, like milk, wool, etc.

FEEDING STANDARDS.

Grouven's Feeding Standards. The first attempts to formulate the amounts of food components required by farm animals into a definite numerical expression are the feeding standards proposed by Grouven in 1858 (7), viz., standards for calves, milch cows, working and fattening oxen, horses, sheep and swine, according to their respective live weights. These standards showed the quantities of dry substance, protein, and fat, which an animal of a certain weight would require daily in its feed ration. For milch cows, weighing 450 kilos (992 lbs. avoirdupois), the following standard was proposed by this investigator:

28.7 lbs. dry matter, 2.76 lbs. protein, .86 lbs. fat, 14.55 lbs. carbohydrates, the proportion between the nitrogenous and non-nitrogenous components being 1:6.1.

Eight standards were proposed for milch cows, according to the live weights of the cows, ranging from 772 lbs. (350 kilograms) to 1,543 lbs. (700 kilograms).

The system of hay values had by this time been abandoned by most authorities and writers on agricultural topics and it was generally agreed, as is now the case, that the standard set in this system, that of meadow hay, is subject to too great variations to serve as a correct basis for comparison. During recent years a modification of this system has, however, sprung up in north European countries, the so-called "food units," as a matter of convenience in determining the approximate amounts of feed which a herd or individual animals therein receive during a given period, generally a year, and the economy of the production of the animals for this time.*

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*The feed stuffs are referred to a common food unit, one pound of concentrated feeds like cereals, mill-refuse feeds, etc., and this quantity is supposed to possess a similar food value as 2½ to 3 lbs. of good meadow hay, 4 lbs. of hay of poorer quality, 10 lbs. of rutabagas, 12½ lbs. of turnips, 10 lbs. of green fodder, etc. (8). These figures have of late been largely used in the calculations of the cost of production in case of dairy control associations in the countries referred to. They must be considered more valuable than the old hay values, as they are the deductions of results obtained in a large number of carefully-planned and executed practical feeding trials with cows and swine, conducted by the Danish investigator Fjord, and give expression of the replacemet values of different feeding stuffs when fed in ordinary normal mixed rations. The food units do not, however, in their essence differ from the Thaer hay values and can only be considered approximations. No claims for scientific accuracy, therefore, can be or are made for them.

About the time Grouven's standards were published, digestion experiments with farm animals were conducted for the first time, in which the proportions of the various food components of feeding stuffs which the animal would render soluble by its digestive juices were accurately determined. These experiments soon accumulated, especially after the establishment of the German system of experiment stations for the study of agricultural problems, and much light was shed on the intrinsic value of different feeding stuffs through the results thus obtained. It became evident that the proximate analysis of feeding stuffs might give a very unreliable and misleading clue to their value for feeding purposes, and it was natural, therefore, that the feeding standards for the different classes of farm animals should be changed to show the requirements of digestible nutrients, instead of crude food materials, as before.

Wolff Feeding Standards. This was done by Emil v. Wolff in the standards that bear his name. The Wolff standard rations were published in their present form for the first time in 1864 (9). Wolff, who in 1849 had been appointed the first director of the first Experiment Station in Germany (and in the world), at Moeckern, Saxony, was soon recognized as one of the leading agricultural chemists of Germany; through his works on feeding of farm animals (10), and through the publication of the standards in the annual Agricultural Calendar of Mentzel and v. Lengerke, the main reference book of progressive and educated German farmers, the feeding standards that bear his name gradually became familiar to farmers and became quite generally recognized as the standard guide in feeding farm animals. The Wolff standard ration for milch cows is as follows:

Dry matter 24.50 lbs., digestible protein 2.5 lbs., digestible carbohydrates 12.5 lbs., digestible fat .40 lb.; total digestible substances 15.40 lbs.; nutritive ratio: 1:5.4.

For the reasons suggested, the Wolff standards became more widely known and adopted than any other feeding standards proposed by other German scientists; of these the standard for milch cows proposed by Julius Kühn (11) may be mentioned here:

Dry matter 20 to 23.5 lbs., digestible albuminoids 1.5 to 2.4 lbs., digestible nitrogen-free extract, crude fiber and amides 12 to 14 lbs.; nutritive ratio: 1:5.5 to 8.

Concerning the special claims to recognition of the Wolff and Kühn standards a long-continued controversy was waged by the respective authors, as to the advisability of placing the nutrients required by farm animals at absolute rigid values, irrespective of the production of the animals fed or their individual characteristics, and of basing the calculation of the valuable components in food stuffs on the average composition as obtained by chemical analyses of different numbers of samples of the various feeds, as is advocated by Wolff, thus allowing no variation according to the character of the feeding stuffs on hand, whether of good, medium or poor quality.*

Wolff-Lehmann Standards. The former criticism of the Wolff standard ration for milch cows was met by the publication of the modification of this standard in 1897 after the death of the author, by C. Lehmann of Berlin (12). The quantities of nutrients to be supplied in the daily rations for maximum production, in case of cows yielding from 11.0 to 27.5 lbs. of milk daily, are specified in the rations as shown by the following statement.

Wolff-Lehmann feeding standards for dairy cows.

	Total dry matter.	DIGESTIBLE NUTRIENTS.			Nutritive ratio.
		Protein.	Carbohydrates.	Fat.	
When yielding daily:	Lbs.	Lbs.	Lbs.	Lbs.	1:
11.0 lbs. of milk	25.	1.6	10.	0.3	6.7
16.6 lbs. of milk	27.	2.0	11.	0.4	6.0
22.0 lbs. of milk	29.	2.5	13.	0.5	5.7
27.5 lbs. of milk	32.	3.3	13.	0.8	4.5

The Wolff-Lehmann feeding standard, as it is now generally called, takes into account the production of the cows as regards the quantity of milk yielded. By dividing the amounts of dry matter and digestible components by the number of pounds of milk in each case we find that for every pound of milk the rations call for 1.2–1.3 lbs. dry matter, .11–.15 lb. digestible protein, .47–.91 lb. digestible carbohydrates, and .02–.03 lb. digestible fat.†

Since milk containing a high per cent of fat is also rich in other solids, it is natural to suppose that the production of a certain unit

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*A general discussion of the subject of feeding standards, in which the Wolff standard ration is particularly subjected to criticism, is given by J. Kühn in a special article entitled "Feeding Standards for Domestic Animals," in *Experiment Station Record* (Vol. 4, pp. 6–13), to which reference is here made.

†*Pott* publishes a similar series of standards for dairy cows yielding from 11 to 44 pounds of milk a day or more; minimum, maximum and average figures are given for the amounts of dry matter and digestible components to be supplied according to the production of the cows, the average amounts of dry matter ranging from 26 to 28 pounds, of digestible protein from 2.2 to 3.5 lbs., and of total digestible matter from 12.2 to 17.7 lbs., per day and per thousand pounds live weight. For dry cows near calving the following standard is given: dry matter 22 lbs., digestible protein 1.7 lbs., digestible carbohydrates 7.5 lbs., and digestible fat .4 lb. (*Handb. d. tier. Ernährung*, I, Berlin 1904, p. 374.)

of such milk will require a larger supply of nutrients than is necessary for the production of the same quantity of milk of a low content of fat and total solids. The amount of nutrients required for the production of milk of different quality has been determined in the case of a small number of cows by Professor Haecker (13), who found the digestible protein in the food required per pound of milk testing 2.5 per cent to be .036 lbs., and for milk testing 5.5 per cent .057 lbs., the corresponding figures for carbohydrates being .16 and .26 lb., and for fat .012 and .019 lb. On basis of these data Haecker calculates the amounts of nutrients that should be furnished per pound of milk in the feed rations of cows producing 2.5 to 7.0 per cent milk, over and above those required for the maintenance of the body of the cows which are placed at .07 lb. digestible protein, .7 lb. digestible carbohydrates and .01 lb. digestible fat per hundred pounds of body weight. We shall later consider the evidence presented by this author in the bulletin referred to and the deductions made from the same, and shall not therefore discuss these data at this point.

The Maercker Standard Ration. The Wolff–Lehmann and the Kühn standard rations are the only standards that are generally accepted by European authorities at the present time. In 1889 Maercker recommended, on basis of the results of experiments conducted by him, a more intense protein feeding than that called for by the Wolff or the Wolff–Lehmann rations (14), viz., for cows weighing 500 kilos, from 1.25 to 2.026 kilograms (calculated per thousand pounds live weight, from 2.5 to 4.05 lbs. digestible protein), and a nutritive ratio of 1:3.6. This high protein feeding, it was argued, would be financially advantageous under our modern system of intensive dairy farming with improved breeds of dairy cows that can utilize large quantities of feed, both from a resulting increased milk production and on account of the increased value of the stable manure thus produced. Maercker's recommendations do not, however, appear to have been adopted by German or other dairy farmers, or accepted by authorties on the subject of animal nutrition; experiments by H. Wirth, among others, have also shown that such intensive feeding does not give economical returns (15).

The Feeding Standards in America. The Wolff feeding standards were introduced to our American public by Atwater in 1874 (16), and more effectively, by Armsby through the publication of his "Manual of Cattle Feeding," in 1880. They soon became well-known among students of agriculture, and writers and lecturers on agricultural topics, as well as among progressive farmers throughout the country.

Up to the beginning of the nineties it was generally believed that these standards were equally applicable to our American conditions as to those of European countries and that they might be recommended to our farmers as a safe guide in the feeding of farm animals. A preliminary study conducted by the writer in 1892 as to the character of the rations which leading dairy farmers in this state fed their cows, gave decided evidence, however, that under the conditions prevailing in this state, at least, dairy cows kept under the best conditions were not fed as much protein nor as narrow nutritive ratios, as is called for by the Wolff feeding standard. The average of fifteen different rations gave 2.2 lbs. digestible protein, 13.16 lbs. digestible carbohydrates and .76 lb. fat, the nutritive ratio being 1:6.9. Of the 15 dairymen only four fed 2.5 lbs. or more of digestible protein per day to mature cows in full flow of milk, and only three fed 5.4 lbs. digestible non-nitrogenous substances (carbohydrates plus fat multiplied by 2.25) or less, for every pound of digestible protein in the ration (17).

During the following year the investigation was extended to include prominent dairymen in all parts of the Union and in Canada, the effort being to secure as accurate information as possible as to the kinds and amounts of feeds which these fed their cows, as well as the average production, live weight and breeds of cows. The main results of this investigation were published in Bulletin 38 of this Station (18). Of the 100 rations for dairy cows which were obtained and are published in the bulletin, 29 contained less than 2.5 lbs. digestible protein, and only 16 had a nutritive ratio of 1:5.4 or less. Combining these rations with those ascertained in the study of the system of feeding practiced by Wisconsin dairymen and with two series of rations published by the Geneva, New York, (19), and the Connecticut (20) Experiment Stations, the following average ration was arrived at:

Dry matter 24.51 lbs., digestible protein 2.15 lbs., digestible carbohydrates and fat 14.51 lbs.; nutritive ratio 1:6.9.

This ration embodies the experience of more than one hundred prominent American dairymen, as regards the amounts and the character of the feed which under our American conditions will be likely to give the best and most economical results when fed to good dairy cows in full flow of milk and of an average weight of 1,000 pounds. The name of the American practical feeding ration was suggested for this average ration and its adoption was recommended to our farmers in preference to the German standard which had so far been considered a reliable guide by American writers and speakers on dairy topics.

During the ten years or more that have elapsed since the publication of this American practical feeding ration, a large amount of evidence has been brought forward by our experiment stations, bearing on the subject of feeding dairy cows which will be briefly referred to in the following pages. On the whole, it may be said that the testimony offered has fully corroborated the conclusions drawn by the writer in the publications cited, viz., that under ordinary conditions on dairy farms in this country, particularly under the normal condition of our feed market in the central western states, the most profitable rations for dairy cows contain less protein and are of a wider nutritive ratio than specified by the German feeding standard.

Fuel Value of Rations. During late years some writers on the subject of animal nutrition have adopted the practice of calculating the fuel value of rations for dairy cows, on basis of the isodynamic values of different nutrients obtained by Stohmann and Rubner with man or carnivora, and it is taken for granted that the figures thus obtained may also be used to represent the total energy of the different rations for production by the former class of animals. It would seem, however, that our present knowledge of the metabolic processes and the utilization of the energy of food materials for production by ruminants, especially by milch cows, is not sufficient to warrant the use of data obtained with other classes of animals for this purpose. If reliable, the method would furnish a convenient means of expressing in a single figure the potential efficiency of different feed rations, but unfortunately it does not rest on a sufficiently broad and firm scientific basis, so far as our present knowledge goes, to be of much value either to the student of dairy husbandry or to the practical dairy farmer. It may not be out of place to recall here the remarks made only a few years ago in regard to this point by the scientist whose work in this line entitles him to speak with more authority than any other man living. "It seems indeed, says Dr. Kellner, that the less many have accomplished in the line of independent experimental research, the greater is their courage to construct systems with scientific appearances out of nothing, and the greater is at the same time their disrespect for the advancement to which the earnest labors of another have led." (21).*

The difference between and relative claims to recognition of physiological feeding standards, like the Wolff–Lehmann or Kühn rations, and the average feeding ration will be discussed in a later part of this bulletin. Having sketched briefly the progress made in our knowledge of cattle foods and current views as to the requirements of dairy cows for nutrients, we shall now consider somewhat in detail in how far the production of milk and butter fat by dairy cows can be affected by the character of the feed, and its relation to the quantity and quality of the milk production of dairy cows.

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*See also Armsby, The Isodynamic Replacement of Nutrients, in *Science*, Oct. 16, 1903.

INVESTIGATIONS CONCERNING THE RELATION OF FOOD TO MILK PRODUCTION.

Numerous investigations have been conducted during the past few decades in this country and abroad bearing on the question of the relation of the food of dairy cows to the character and amount of their production of milk and milk components. With the growth of our dairy interests during the past generation it is only natural that such should be the case. There are in this country at the present time more than eighteen million milch cows that furnish milk for direct consumption or for the manufacture of butter, cheese or condensed milk. The annual value of the dairy products manufactured in this country during the census year of 1900 was nearly half a billion dollars and the value of the cows, two years old and over, that produced this amount, another half billion dollars (22). The dairy products produced in each of six states in the Union, Wisconsin being one of this number, at that time were worth more than twenty-five million dollars annually. The attention of stations and dairy scientists to studies looking toward a clearer understanding of the principles underlying the feeding of dairy cows is therefore fully justified. Such studies have been conducted at this Experiment Station nearly every year since its establishment in 1883, and by the writer, alone or with associates, since the year 1888 (23). Some of these investigations do not come within the scope of the problems under discussion in this paper, but many have a direct bearing on these problems and will be briefly reviewed in the following, with the results of similar work done elsewhere at American Experiment Stations or by European investigators. A detailed consideration of these investigations, or even a brief mention of the main results obtained, would not be possible here from lack of space. The principles and broader teachings are of prime importance and our main effort will be to look for such, rather than to give detailed statements of the conduct and results of the investigations referred to.

DIFFICULTIES MET WITH IN EXPERIMENTS WITH DAIRY COWS.

When we examine the testimony as to the effect of the character of food on the dairy production, it will soon become evident that many of the experiments with milch cows which have been conducted in the past are of a very doubtful value and, in many cases, may safely be excluded from consideration, for one of several reasons. The most frequent error of earlier cow-feeding experiments was that they were conducted with a small number of cows, generally only one or two, and for a brief period of time, often for only a couple of weeks, without any introductory or intermediate feeding periods during which the cows might become accustomed to the system of feeding adopted. The individual characteristics of animals differ greatly, to such an extent that exactly opposite conclusions may often be drawn from the results of feeding a certain feeding stuff or combinations of feeds to two cows placed under otherwise apparently similar conditions. (24). This is now recognized by many investigators. Ramm thus concludes from the results of feeding experiments with milch cows conducted by him, that the effect of the food is dependent upon the individuality of the animals. "It often happens that the same feeding stuff causes an entirely opposite effect in the case of one animal than in the case of another;" and Thorne says in discussing cow-feeding experiments (25), "The necessity for dealing with large numbers of individuals in the study of questions pertaining to animal life and nutrition is exemplified in every test under review. It would seem that experiments including two or three individuals only are scarcely worth the making." (See also p. 57 and p. 65.)

Any change in the system of feeding is, as we shall see, generally accompanied by an immediate disturbance of the normal character of the production of cows, and it is only after some time has passed, the length of which will vary with different animals, from a few days to several weeks, that the system of the animal is able to adjust itself to the change in the feed ration. The results of many of the early cow-feeding experiments cannot for this reason furnish definite information in regard to the effect of single feeds or combination of feeds on the milk production, and are of no value as aids in the solution of problems of this character.

Hills concludes from studies which he made as to the proper length of feeding trials with milch cows (26), that feeding periods four weeks long may give trustworthy results as regards changes in quantity, while six-week periods and those yet longer in duration may be required to obtain satisfactory results as to the quality of milk produced by the feed experimented with. On the other hand, Thorne gives as his opinion, (27), that "We need to expand the 90–day test into a 12-month test, and the 12-month test must grow into observations extending over the entire lifetime of a very large number of individuals before perfection in this work is attained. We might as well drop the three or four–week test altogether."

A further difficulty in studying this subject arises from the fact that the published data in connection with many experiments are often incomplete or do not furnish sufficient detailed information on points of importance in the present discussion to be of any value for our purpose. For the reasons suggested, experiments for the study of the influence of food on the milk secretion need to be carefully planned and many safeguards as to the number of animals included on the experiment, duration of the experimental periods, management of the cows, etc., must be observed in order to secure results that will give a true expression of the effects of the foods experimented with and will permit of generalization.

Of the large number of feeding experiments with milch cows which will bear scrutiny in these various ways and in case of which fairly complete experimental data are also published, many deal with problems that do not throw light on the question of the influence of the ration on the milk production, but many experiments, the results of which have been published, do furnish evidence along the lines of inquiry covered by this subject, and the amount of reliable material available is, it would seem, still sufficiently abundant to warrant our drawing definite conclusions on many problems that present themselves in connection with the relation of food and the production by dairy cows.

DUAL OFFICE OF FOOD.

The animal organism uses the nutrients contained in the food for one or two purposes, viz., (1), for maintenance, to replace the energy lost in the form of heat, through radiation, evaporation, etc., and to repair the waste of cell tissues incident to the vital processes, and (2) for production of work or animal products like meat, milk, wool, etc. It is essential for continued production that the supply of nutrients in the food shall be more than sufficient to cover the needs of the organism for maintenance, and it is therefore, under normal conditions, only the nutrients supplied in excess of maintenance requirements which contribute toward the building up of new tissues or production of work, milk, etc. The instinct of the preservation of the race is, however, stronger than that of the preservation of the individual, and if, for instance, a cow in milk does not receive an amount of food more than sufficient to cover the needs of her own body, her production will not cease, but she will take the material required for this production from her own body tissues, hence her weight will gradually decrease; the milk produced under such conditions will not be of normal character, but will be of poorer quality than is ordinarily the case. (See p. 63.)

In the study of the relation of food to milk production the general practice has been to consider the total effect of the food for maintenance and for production. Where the object in view is to ascertain the economy of certain combinations of feeding stuffs, this method is doubtless a rational one, since, as has been pointed out by Armsby, among others (28), the feeder must pay for the food required for the maintenance of his animals as well as for that portion which serves for productive purposes. But in case of a study of the principles which determine the utilization of the food for production, that is, the relation between food and production, a consideration of the total effect of the food would evidently only tend to conceal the laws that determine the uses which the animal makes of the productive portion of the food. We shall, therefore, in this bulletin mainly discuss the relation between the milk production of the cows and the excess food over and above maintenance requirements. Preparatory to a discussion of this subject it will be necessary to consider briefly the maintenance ration of dairy cows.

THE MAINTENANCE RATION FOR DAIRY COWS.

A definite knowledge of the maintenance requirements of dairy cows is necessary for a correct understanding of the relation of food and production by dairy cows. By the term *maintenance requirements* is meant the amount of food materials that will keep an animal in a healthy, active condition without causing either a gain or a loss in the body weight of the animal. From the fact that dairy cows under normal conditions are either producing milk or furnishing nutriment for the growth of a foetus, it is a matter of considerable difficulty to obtain information on this point with reference to this class of animals, and we are left largely to judge by analogy from the results of investigations of the food required for the maintenance of steers. Experiments along this line by Henneberg and Stohmann in 1858 (29), led Wolff to formulate the standard for the maintenance of cattle, which is perhaps best known and has been more widely accepted than any other, viz., .7 lb. of digestible protein, 8 lbs. digestible carbohydrates and .1 lb. digestible fat, per thousand pounds weight and per day (30).

In experiments reported from the New Hampshire Agricultural College in 1879 (31), Sanborn showed that steers fed timothy hay in the amounts called for by this standard gained in live weight, and Caldwell of Cornell Experiment Station (32), in a trial with four steers, obtained an increase of 180 lbs. in weight during a feeding period of 60 days, on a ration containing .68 lb. digestible protein and 8.6 lbs. carbohydrates and fat. G. Kühn also showed in carefully-planned and executed experiments that the Wolff maintenance standard was in excess of the actual requirements of mature steers kept in perfect quiet in the stall. Under these conditions he found that the animals can be maintained in weight on .7 lb. digestible protein and 6.6 lbs. digestible nitrogen-free extract per thousand pounds live weight (33). Haecker of the Minnesota Experiment Station, on the other hand, experimenting with barren dry cows, showed that a daily allowance of .63 lb. digestible protein, 5.75 lbs. digestible carbohydrates and .12 lb. ether extract, per thousand pounds live weight, resulted in a daily average gain of about one-quarter of a pound (34), and suggests tentatively that the food of maintenance for barren dry cows, when at rest in stall, be expressed in nutrients as .6 lb. protein, 6.0 lbs. carbohydrates and .1 lb. fat per thousand pounds live weight, and that when at work in a dairy with ordinary good care and comfortable quarters, 12.5 lbs. dry matter, .7 lb. protein, 7 lbs. carbohydrates and .1 lb. fat be allowed per thousand pounds live weight; reducing the fat to its starch equivalent, this is equal to 7.23 lbs. non-nitrogenous digestible constitutents calculated as starch.

These latter figures may be safely assumed to represent quite closely the acual maintenance requirements of dairy cows as generally kept under modern conditions of dairy farming in this country and we shall make use of them in the following. It should be noted, however, that as has been shown by Armsby (35), the value of a given feeding stuff for maintenance depends on the amount of net available energy which it furnishes to the animal; if a large share of the metabolizable energy of the feeding stuff is consumed by the work of digestion and assimilation, e. g. in the case of straw, hay and other coarse fodders, a certain quantity of digestible matter contained therein will be of less value to the animal than the same amount present in a concentrated feeding stuff, in the case of which only a small portion of the gross energy is required in the process of mastication, digestion and assimilation by the animal body. The maintenance requirements suggested, therefore, only hold true with rations of a character similar to those experimented with, which were made up largely, and in some cases wholly, of coarse fodder, hay or fodder corn, with only a small amount of grain (36).

THE PRODUCTIVE PORTION OF THE FOOD.

The portion of the nutrients supplied in excess of the maintenance requirements is utilized by the dairy cow in at least one of three different ways; (1) for bodily growth, in the case of young animals, (2) for the production of milk, or (3) for the production of body fat. We are here mainly concerned with the last two uses of the food, since dairy cows, two years old or over, have for the greater part made the growth that they will reach. The normal use of the productive portion of the food of the dairy cow is for milk production, and a good dairy cow cannot, as a rule, be fattened when in full flow of milk. However, with a wrong system of feeding, when large quantities of highly carbonaceous feeds are given, or with cows of strong " beefy" (fattening) tendencies, in which the dairy characteristics are not greatly developed, the excess food is often used for this purpose; in such cases the milk secretion necessarily suffer; i. e., it will be smaller than would be the case if all the digested food in excess of maintenance requirements could be utilized for the production of milk alone. We shall have occasion to refer to this subject later on under the discussion of type in cows and shall then examine into the productive capacities of cows of different types and the relative economy of their production as regards food consumption. At the present we shall consider the question of the uses which the dairy cow makes of the food eaten.

It is well-known that the maximum production of milk by a dairy cow comes shortly after parturition, viz., from one to four weeks, varying with different cows, and with the system of feeding practiced. Normally the maximum production of milk in a modern dairy herd will come at about the third week after calving and the maximum production of butter fat during the second week (37). It follows, therefore, that the quality of the milk produced, as regards its fat content, is better, as a rule, during the first and second week after parturition than for many weeks to come and only reaches a similar percentage late in the lactation period when the flow of milk has been greatly decreased.

The average normal decrease in the production of milk and butter fat in a modern dairy herd has been determined by Sturtevant, who found a natural falling off for each month after calving of about 9 per cent in the yield of the preceding month (38). Linfield observed a similar, quite constant decrease of about 9 per cent in the average milk yield of 16 cows in the Utah Experiment Station dairy herd, up to the sixth month after calving, while from this period to the end of the lactation the production of milk decreased by 12 per cent for each month (39). May of Kentucky found the average shrinkage in the flow of milk during the entire milking period for cows in the herd of that experiment station, 8.1 per cent per month and of fat 7.4 per cent (40), while Carlyle and the writer obtained an average decrease of 8 per cent in the milk production and 7.3 per cent in the fat production per month, as the average of records for four years including about 80 lactation periods (41). As the average of four years' observations, Beach, in the same way, found the monthly shrinkage in milk yield to range from 4.5 to 8.5 per cent during the first eight months of the lactation period and 13.3–14.2 per cent during the 9th and 10th month; average for the entire period, 8.1 per cent (42).

The Wolff-Lehmann feeding standard, which may serve as a convenient basis for calculation in the present discussion, provides that a cow in full flow of milk yielding 22 lbs. of milk a day at the middle of her lactation period "or at least two months after calving and giving milk of an average composition", shall receive 29 lbs. dry matter, 2.5 lbs. digestible protein and 13.13 lbs. digestible carbohydrates and fat. If we assume the maintenance requirements of a thousand-pound cow to be 12.5 lbs. dry matter, .7 lb. digestible protein and 7.23 lbs. digestible carbohydrates (see page 15), we arrive at the following productive ration of a cow fed according to the Wolff-Lehmann standard: 16.5 lbs. dry matter, 1.8 lbs. digestible protein and 6.9 lbs. digestible carbohydrates and fat. The following net nutrients would, therefore, be required per *hundred pounds of milk*,

75 lbs. dry matter, 8.2 lbs. digestible protein, and 31.4 lbs. digestible carbohydrates and fat.

On the supposition that the milk contained 3.7 per cent fat, the daily production of fat of this cow would be .814 lb., and there would therefore be required for the production of *one pound of fat*,

20.2 lbs. dry matter, 2.21 lbs. digestible protein, and 8.47 lbs. digestible carbohydrates and fat.

These figures do not, however, correctly represent the utilization of food by dairy cows as fed and managed under modern American conditions; they are much too high, as will be evident from the statements of experimental data on this point given in the following pages.

In the elaborate investigation reported in Bull. No. 102 of this Experiment Station,, "Studies in Milk Production", by the writer working in conjunction with Professor Carlyle, are recorded data obtained for the production and food consumption of thirty-three different cows during one to five winter periods, Nov. 15–May 15. The following table contains the main facts concerning the relation of food to production which are given in this bulletin or have been obtained from the original records, all recalculated and verified. As the point in view in the discussion given in the bulletin differs from our present inquiry, it was necessary to vary from the method of calculation adopted in the bulletin, in which the production and food consumption for the entire year or half-year periods was considered, and the average production and amount of food eaten for each day during which the cows gave milk were here used as a basis for the calculation. For this reason the figures given in the following table differ in some cases considerably from those found in the tables on pages 76–77 of the bulletin referred to. The data for net nutrients given in the table are averages for the entire period and a small error is therefore introduced in these figures in the case of cows that did not give milk during this whole time, for the reason that the cows received less food when dry than when in milk. It is not believed that the error thus introduced is of sufficient importance to be worth considering, except perhaps in the case of two or three cows which were dry during a considerable portion of the winter periods.

We give below the average daily production of the cows and the food materials contained in the rations fed to the different cows during the winter half-year, the records including from one to five years in case of the various cows. The cows are arranged according to the average amount of fat produced per head and per day.

The figures in the columns of the table headed "Net nutrients" have been obtained on the supposition that the various cows required food materials for the maintenance of their bodies in direct proportion to their live weights, and that the amounts of nutrients required for the maintenance of a cow weighing 1000 pounds were 12.5 pounds dry matter, .7 pound digestible protein and 7.23 pounds digestible carbohydrates and fat.

Average production and food consumption, in pounds.

NAME OF COWS.	Milk, per day.	FAT, PER DAY.		NET NUTRIENTS.			NET NUTRIENTS PER 100 LBS. MILK.			NET NUTRIENTS PER 1 LB. FAT.			Days in milk.	Live wt., lbs.
		Yield.	Per cent.	Dry M.	Protein.	Carbh. and fat.	Dry M.	Protein.	Carbh. and fat.	Dry M.	Protein.	Carbh. and fat.		
Group I.														
Gold	22.4	1.43	6.38	16.6	1.45	10.67	74.1	6.47	47.6	11.6	1.01	7.46	182	806
Lady.	30.7	1.27	4.14	14.8	1.50	9.16	48.2	4.89	29.9	11.7	1.18	7.21	180	1,142
Alma	39.2	1.22	3.11	15.4	1.66	9.95	39.3	4.13	25.4	12.6	1.36	8.16	174	989
Murphy	22.3	1.22	5.47	12.6	1.16	7.67	56.5	5.20	34.4	10.3	.95	6.29	173	861
Goodrich ...	25.5	1.21	4.75	13.8	1.38	8.59	54.1	5.42	33.7	11.4	1.14	7.11	182	758
Lizzie	23.9	1.21	5.06	10.2	1.01	6.35	42.7	4.23	26.6	8.4	.83	5.25	179	998
Donation ...	33.9	1.21	3.57	9.6	1.08	5.95	28.3	3.19	17.6	7.9	.89	4.92	151	1,217
Maud	30.8	1.20	3.90	11.7	1.15	7.25	38.0	3.73	23.5	8.0	.96	6.04	156	1,117
McGeoch....	30.9	1.18	3.82	9.3	1.25	5.74	30.1	4.05	18.6	7.9	1.06	4.87	147	1,194
Nan	24.2	1.18	4.88	14.1	1.26	8.68	58.3	5.21	35.9	12.0	1.07	7.36	162	769
Bessie	24.8	1.16	4.68	12.1	1.26	7.48	48.8	5.08	30.2	10.4	1.09	6.45	182	854
Average...	*28.1*	*1.23*	*4.38*	*12.7*	*1.29*	*7.96*	*45.2*	*4.59*	*28.3*	*10.3*	*1.05*	*6.47*	*170*	*973*
Group II.														
Joe..........	33.9	1.15	3.39	15.5	1.89	8.55	45.7	5.57	25.2	13.5	1.64	7.37	183	1,056
Dora	24.9	1.11	4.46	11.1	1.14	6.90	44.6	4.58	27.7	10.0	1.03	6.22	182	1,003
Chloe	30.8	1.10	3.57	10.1	1.52	7.40	32.8	4.94	24.0	9.2	1.38	6.73	182	1,277
Rose	22.3	1.06	4.75	9.1	1.02	5.78	40.8	4.57	25.9	8.6	.96	5.45	145	1,208
Duchess	23.4	.99	4.23	10.5	1.12	6.91	44.9	4.79	29.5	10.6	1.13	6.98	178	1,288
Pauline	25.0	.99	3.96	6.7	.79	4.72	26.8	3.16	18.9	6.8	.80	4.77	169	1,286
Ella	18.1	.97	5.36	7.7	.76	4.74	42.5	4.20	26.2	7.9	.78	4.89	149	1,026
Reba	17.8	.96	5.39	10.5	.73	5.03	83.4	5.79	39.9	16.2	1.12	7.74	128	863
Laura . ..	17.2	.93	5.41	13.8	1.56	8.53	80.2	9.07	49.6	14.8	1.68	9.17	183	909
Brownie	17.5	.93	5.31	10.7	1.03	6.60	61.1	5.89	37.7	11.5	1.11	7.10	167	1,033
June	24.0	.89	3.71	12.8	1.32	7.98	53.3	5.50	33.3	14.4	1.48	8.97	161	1,005
Average ..	*23.0*	*1.00*	*4.35*	*10.3*	*1.13*	*6.39*	*44.8*	*4.91*	*27.8*	*10.3*	*1.13*	*6.39*	*163*	*1,099*
Group III.														
Hill	20.9	.88	4.21	16.4	1.50	10.26	78.5	7.18	49.1	18.6	1.70	11.66	182	1,021
Dolly	17.3	.88	5.09	8.8	1.14	5.69	50.9	6.59	32.9	10.0	1.20	6.47	182	1,091
May	15.4	.87	5.65	7.9	.78	4.99	51.3	5.06	32.4	9.1	.90	5.74	152	945
Campbell ..	22.4	.86	3.84	8.1	.84	5.13	36.2	3.75	22.9	9.4	.98	5.97	122	1,137
Princess	23.1	.86	3.72	9.8	1.03	6.63	42.4	4.46	28.7	11.4	1.20	7.71	164	1,094
Dorine	15.2	.81	5.33	6.4	.75	3.85	42.1	4.93	25.3	7.9	.93	4.75	138	857
Muriel	12.6	.78	6.19	6.7	.77	4.04	53.2	6.11	32.1	8.6	.99	5.18	153	821
Hoard	13.5	.77	5.70	9.2	1.07	5.62	68.2	7.93	41.7	11.9	1.39	7.30	171	806
Dixie	21.2	.76	3.58	9.3	.78	3.24	43.9	3.68	15.4	12.2	1.03	4.26	120	1,130
Molly	20.1	.72	3.58	11.5	.92	5.27	57.2	4.58	26.2	16.0	1.28	7.32	183	1,210
Belle	14.1	.61	4.33	6.1	.71	3.79	43.3	5.04	26.9	10.0	1.16	6.21	145	1,327
Average ..	*17.9*	*.80*	*4.47*	*9.5*	*.97*	*5.75*	*53.1*	*5.42*	*32.1*	*11.9*	*1.21*	*7.19*	*159*	*1,028*

The great variations in both the average production of the different cows, the net nutrients in their rations, and the food required for the production of a unit of milk or butter fat as shown in this table, are very striking. For the winter periods considered we have a minimum average production of 12.6 lbs. milk and of .61 lb. fat, and a maximum production of 39.2 lbs. milk and 1.43 lbs. fat. The smallest amounts of net nutrients required by a cow per hundred pounds of milk produced were 26.8 lbs. dry matter, 3.16 lbs. digestible protein and 15.4 lbs. digestible carbohydrates and fat, and per pound of fat in the same order 6.8 lbs., .78 lb. and 4.26 lbs., while the maximum amounts of net nutrients required were from two to three times larger. As the average for 33 cows, including data for 88 winter periods in all, we have the following data:—

Net nutrients required for the production of a unit of milk and butter fat.

	Net dry matter.	Dig. protein.	Dig. carbh. and fat.	Total dig. matter.
Per hundred lbs. milk.............	48.9 pounds	5.06 pounds	29.7 pounds	34.76 pounds
Per lb. fat........................	10.8 pounds	1.12 pounds	6.54 pounds	7.66 pounds

We notice a marked difference between these figures and those deducted from the Wolff-Lehmann standard. Considerably less dry matter and digestible protein were required, both for the production of a unit of milk and of fat under the system of feeding practiced in our dairy herd, which it may be stated, is similar to that adopted by the best dairymen in this state and in the Northwest generally, and may be considered a most economical system under present conditions in this section of our country.

The accompanying diagram (Fig. 1) will serve to bring out clearly the relation between the production of butter fat to the net nutrients in the form of dry matter required for the production of hundred pounds of milk and of one pound of fat by different cows. There is apparently no definite relation between the production of butter fat and the amount of food required to produce a unit of milk or butter fat in the case of individual cows, and it is plain that a low-producing cow does not necessarily require a large amount of food per unit of production, nor a heavy producer a small amount; but when the general tendency of the curves for dry matter per unit of milk and butter fat is noted, it will be seen that the results show conclusively that low-producing cows require more food for a unit of products than do cows that are heavy producers.

If the cows included in the last but one table be separated into three groups according to their average production, we obtain the data for high, medium and low producers, given in the table as *Averages*.

These results should throw some light upon the relative utilization of food by cows of different dairy capacities. They suggest with considerable emphasis that the highest producers among the cows were also, on the whole, the most economical ones, since these cows used about 15 per cent less of the productive portion of the ration for the manufacture of a unit of milk or butter, while medium producers required an intermediate amount between those for high and low producers. These results were not obtained with a sufficiently large number of animals or under sufficiently varied conditions to permit of generalization, but they are doubtless true expressions of the approximate relation between food and production in case of good dairy cows fed and kept according to modern principles of dairying.

VARIATIONS IN THE FOOD REQUIREMENTS OF DAIRY COWS.

If the detailed results obtained with the cows in our University herd during the five winter periods, 1898–1903, are studied, perhaps the most noticeable feature about them will be the great variations occurring in case of different animals; in carrying the investigations one step further we note that variations almost as large are found during different periods with the same animals. The detailed results showing the food requirements with the various cows in our herd during successive years are given in the Appendix.

Comparison of average results obtained with cows in the University herd.

	MINIMA.		MAXIMA.	
	Per 100 lbs. milk.	Per 1 lb. fat.	Per 100 lbs. milk.	Per 1 lb. fat.
Comparisons of average results for different animals.				
Net nutrients required:				
Net dry matter, lbs	26.8 (Pauline)	6.8 (Pauline)	80.2 (Laura)	18.6 (Hill)
dig. protein, lbs	3.16 (Pauline)	.76 (Reba)	9.07 (Laura)	1.70 (Hill)
dig. carbh. + fat, lbs	15.4 (Dixie)	4.77 (Pauline)	49.6 (Laura)	11.66 (Hill)
Comparisons of average results for different years.				
Net nutrients required:				
Net dry matter, lbs	14.5 (Belle, 3)*	3.2 (Belle, 3)	111.0 (Dolly, 1)	22.6 (Dolly, 1)
dig. protein, lbs	2.25 (Pauline, 5)	.59 (Pauline, 5)	11.1 (Dolly, 1; Laura, 1)	2.27 (June, 1)
dig. carbh. + fat, lbs	11.2 (Belle, 3)	2.32 (Belle, 3)	69.8 (Dolly, 1)	14.1 (Dolly, 1)

* Number of year in herd.

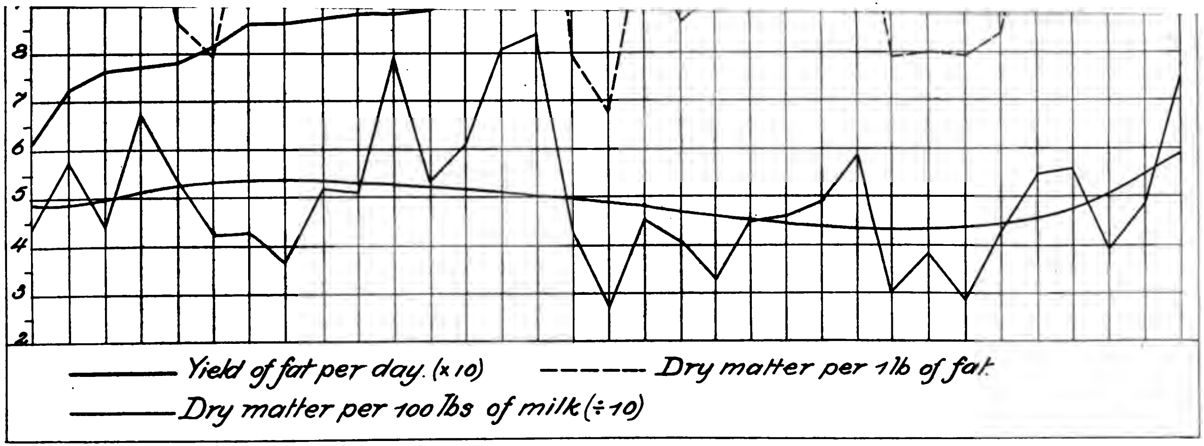

FIG. 1.—Relation between the production of butter fat of cows in the University herd and the food required for the production of a unit of milk or butter fat. The points representing the data for the individual cows are connected by lines so as to guide the eye. The general run of the curves for dry matter per 100 lbs. of milk and per 1 lb. of fat shows that poor cows require more food for the production of a unit of milk or butter fat than do good cows.

The extremes in the amounts of different net nutrients consumed per unit of milk and butter in case of the cows in our herd will be seen in the preceding statement.

The comparisons of the average data for the different animals during their entire life in the herd show that the amount of dry matter consumed above maintenance requirements per hundred pounds of milk ranged between 26.8 pounds and 80.2 pounds (for Pauline and Laura, respectively), while the net amount of digestible protein ranged between 3.16 and 9.07 pounds for the same cows, and digestible carbohydrates and fat between 15.4 and 49.6 pounds (for Dixie and Laura, respectively). In the same way the food materials eaten per one pound of fat produced ranged as follows: Net dry matter 6.8 to 18.6 pounds, digestible carbohydrates and fat 4.77 to 11.66 pounds (in both cases for Pauline and Hill, respectively), and digestible protein .76 pound (Reba) to 1.70 pounds (Hill), i. e. one cow produced a unit of milk or butter fat from one-half to one-third the amounts of food materials required by other cows.

Turning our attention to the latter half of the table we note that the use which cows can make of the productive portion of their feed at any one period is subject to still wider variations, e. g., in the case of the twenty-six cows which were in our University herd for two or more winter periods, the dry matter eaten in excess of maintenance requirements per hundred pounds milk varied from 14.5 in case of Belle (third year) to 111.0 (Dolly, first year), the amount required for the production of one pound of fat varied from 3.2 to 22.6, for the periods given for Belle and Dolly, respectively. Similar differencs, although proportionally not quite so large, were found in the case of the digestible protein, carbohydrates and fat in the rations eaten by the cows.

The extremes as to the requirements of net nutrients for milk and fat production are found in the case of the following cows: *minimum results*, Pauline, Dixie, Belle and Reba; *maximum results*, Laura, Hill, Dolly and June. A careful study has been made of the individual yearly records of these as well as of all other cows in our herd during the past five years and it is believed that a satisfactory explanation of the same can be given in all cases. In order to understand these variations, it will be necessary to analyze the various conditions, that are instrumental in determining the degree of economy with which a cow will be able to transform food materials into milk solids. We shall enter upon such an investigation in the following pages, and in so doing shall have occasion to refer to the abundant testimony which has been accumulated in our University herd during the past dozen years or more, for illustration and study; we shall also draw upon the evidence furnished by other investigations for this purpose in the hope that we may be able to determine with the greatest degree of certainty the importance of the various factors that have a bearing on the utilization of food by dairy cows.

FACTORS DETERMINING THE FOOD ECONOMY OF DAIRY PRODUCTION.

We find a number of conditions entering as factors in the economic production of milk and its constituents by dairy cows, as regards the amount of feed required per unit of milk or butter fat. The main ones among these are the following:

I. The inherent dairy qualities of the cow.
II. The quality of the milk produced.
III. The period of lactation.
IV. The age of the cow.
V. The character and the amount of the feed ration.

I. INHERENT DAIRY QUALITIES OF THE COW.

By the somewhat vague and unsatisfactory term "inherent dairy qualities" of the cow we understand the faculty of a cow to utilize her food for dairy production, to respond to liberal feeding by yielding the largest amount of milk of which she is capable, without at the same time gaining materially in weight through formation and storing of fatty tissue in her body. The food which a mature cow eats may be utilized for one or two purposes: for the production of milk or increase in live weight, or both. Cows which through hereditary tendencies and environment (including feed) have developed a capacity for transforming large quantities of feed into milk, without at the same time utilizing for an increase in body weight any of the feed eaten in excess of that required for the sustenance of the animal, are known as *dairy cows.* Other cows, from influences of the same character acting in another direction, have a capacity for transforming their feed largely into flesh and fat on their bodies, and the milk produced by such cows is utilized entirely for the nourishment of their calves; these are termed strictly *beef cows.* Between these two classes we find a large number of cows that combine the characteristics of the dairy cow, in so far as a large production of milk is concerned, with those of beef cows, in that they produce calves which make profitable feeders for beef production. Cows belonging to this intermediate class are generally spoken of as *dual-purpose* or *farmers' cows.*

Cows belonging to the dairy class proper, as above described, vary considerably in their conformation and characteristics, showing what is termed an extreme dairy type and a large dairy type, which latter may blend imperceptibly into the dual-purpose type. The first of these includes small, much refined and delicate dairy cows with a very spare habit of body. Most of such cows will be found in the Jersey, Guernsey and Holstein breeds, and predominating in these breeds in the order named (43).

In Bulletin No. 102 of this Station, Professor Carlyle and the writer separated the cows in our herd into these three groups: A, *extreme dairy;* B, *large* (strong or robust) *dairy;* C, *dual-purpose cows,* in accordance with the general definitions given above which is further amplified in the bulletin referred to. If we now consider the average data for the various cows in our herd for the periods for which they have been with us, maintaining the same grouping as given in the bulletin, we obtain the summary statement of production and utilization of food given below.

Under Group A—*Extreme dairy,* have been included the following cows: Alma, Bessie, Hill, Dorine, Muriel, May, Gold, Murphy, Goodrich, Hoard, Nan, Beauty, Elsie, Marie.

Under Group B—*Large dairy*—are included Donation, McGeoch, Chloe, Ella, Dora, Lizzie, Brownie, Laura, Reba, Joe, Dolly, Daisy.

Under Group C—*Dual-purpose*—are included Duchess, Pauline, Belle, Princess, Campbell, Molly, Dixie, Maud, Rose, Lady, June, Jane.

Production and utilization of food by cows of different types.

	A.—Extreme dairy.	B.—Large dairy.	C.—Dual-purpose.
Average days in milk during winter periods	168	167	157
Average milk per day, lbs	21.8	24.2	23.4
Average fat per day, lbs	1.05	1.06	.928
Average per cent fat in milk*	4.82	4.38	3.97
Average live weight of cows, lbs	862.	1061.	1177.
Net nutrients required, lbs.			
Per 100 lbs. milk.			
Dry matter	56.8	47.1	43.2
Digestible protein	5.70	5.13	4.38
Digestible carbohydrates and fat	35.3	28.6	25.6
Total digestible matter	41.0	33.73	29.98
Per one lb. fat.			
Dry matter	11.3	10.2	10.8
Digestible protein	1.14	1.12	1.11
Digestible carbohydrates and fat	7.04	6.20	6.49
Total digestible matter	8.14	7.32	7.60

* Av. fat ÷ av. milk × 100.

The differences between the three groups of cows shown in this table are quite striking; we note that cows of the large or strong dairy type gave most milk and butter fat, on the average for each day during which they were in milk during the respective winter periods. As regards the percentages of fat in the milk, average live weight, and net nutrients required for the production of a hundred pounds of milk, they stand between the cows of the two other groups, while they are lower than both these groups, and slightly lower than group C in the amount of net nutrients required per each pound of fat produced.

The correctness of the data obtained as to the net nutrients required for the production of units of milk and butter fat depends on the correctness of the assumption that the amounts of food materials required for maintenance by animals of the same species stand in direct proportion to their live weights. We shall not go into a discussion of this matter here, but shall refer to the question presently in discussing the relation of the period of lactation to the productive capacity of the ration.

Types of Cows. It is not within the scope of this investigation to discuss the relative value of cows of different types for the dairyman, beyond their power to manufacture dairy products from the food eaten, but we may, in passing, call attention to the fact that when the total production of the cows of different types for the entire period during which they were in our dairy herd be considered, as has been done in Bulletin No. 102 of our Station, the large dairy cows yielded the largest net profit of any of the three groups, viz., $45.31 per head, against $43.26 for group A, and $37.82 for group C, the total value of the products being, when the value of the butter is figured at 20 cts. a pound and that of the skim milk at 15 cts. per hundred pounds, $79.98, $84.70 and $77.20, for groups A, B and C, respectively. The difference in the food required for the production of a hundred pounds of milk in case of the different groups is quite large, the figures for the extreme dairy type being the highest, with 56.8 lbs. of dry matter, 5.70 lbs. digestible protein, 35.3 lbs. carbohydrates and fat, and the dual-purpose lowest; there is, however, less difference between groups B and C than between groups B and A.*

Relation between Live Weight and Production. Since the net nutrients required by cows of the three types per hundred pounds milk produced as shown on p. 23 stand in an inverse ratio to the average live weights of the groups, it is important to examine into the relation of the weight of cows to their economy of dairy production. With this object in view the data for the 33 cows whose rations and production have been studied in the preceding have been arranged in three groups according to the average weight of the cows, and the results shown in the following have been obtained.

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*Discussions on the subject of types of cows will be found in bulletins 35, 67 and 71 of the Minn. Exp. Sta. (Haecker), bull. 20 of Storrs (Conn.) Exp. Sta. (Beach), and bull. 68 of the Utah Exp. Sta. (Linfield).

Relation between weight of cows and production.

	Light Cows. (758-945 lbs.)	Medium Cows. (989-1117 lbs.)	Heavy Cows. (1130-1327 lbs.)	Average.
Average weight of cows, lbs.	841	1,040	1,220	1,033
Average milk per day of lactation period, lbs.	19.2	24.9	25.0	23.1
Average fat per day, lbs	1.03	1.03	.98	1.01
Average per cent fat in milk	5.36	4.13	3.92	4.37
Dry matter above maintenance requirements, lbs.				
Per 100 lbs. milk	58.7	49.0	39.3	49.0
Per one lb. fat	10.8	11.5	10.0	10.8

While the quantities of milk produced by cows of different weights appear, on the average, to stand in direct relation to the weight of the cows, the opposite holds true in regard to the percent of fat of the milk; light cows, as a rule, yield considerably richer milk than that produced by heavy cows. The writer has in another place furnished proof that this conclusion will permit of generalization (44).*

Exceptions to the general relation between the fat content of milk produced by cows and their live weights are naturally often found in the case of individual cows, but the evidence at hand points conclusively to a general interrelation between the weight of the animals and the quality of the milk which they produce as stated. Further expla-

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*In a compilation of results of herd tests published by American experiment stations, up to the year 1900, which included yearly records for 191 cows, the cows of each of the various breeds were separated into three groups: *light*, *medium* and *heavy* cows, and the data for each group within the different breeds were then combined into three similar groups, each containing the same number of cows of the various breeds, so as to render the results comparable and eliminating the factor of breed characteristics from consideration. The final results thus obtained were as follows:

	Light Cows	Medium Cows.	Heavy Cows.
Average live weight, lbs.	858	985	1,096
Average annual milk production, lbs.	5,860	6.570	6,449
Average annual fat production, lbs	270.2	287.1	279.0
Average per cent fat	4.61	4.37	4.32

For a difference in live weight of nearly 250 lbs., a difference in the average fat content of the milk of about .3 of a per cent was found, and similar average differences were obtained within the various breeds to which the cows belonged, Jersey, Holstein, Guernsey, Ayrshire, Shorthorn, Devon, and Natives. While these differences are not sufficiently large to account for the constant difference in the composition of, e. g., Jersey and Holstein milk, which we find, it shows that the body weight of a cow is an important factor in determining the quality of the milk she produces. That it is not the sole determining factor is shown, e. g., by a comparison of milk of Shorthorn and Holstein cows.

nations of the results shown in the table on p. 23 will become apparent when other conditions entering into the utilization of food by dairy cows have been considered.

Breed of Cows. The various breeds of dairy cows, which have been gradually developed through the influence of environment and breeding for certain specific purposes, yield milk of characteristic properties, e. g., high in fat and solids not fat, like that of Jersey and Guernsey cows, or milk containing small fat globules of an even size, like that of Holstein cows. It is held by some writers on dairy subjects that a breed characteristic also exists as regards the ability of cows to convert the food eaten in a more or less economical manner into milk products. It is, however, an open question whether this can be considered a characteristic of any one breed. The breed tests which have been conducted in this country and abroad do not supply sufficient evidence to permit of general deductions on this point; on nearly all of these tests, with which the writer is acquainted, only a small number of representatives of the different breeds was included and they were fed, often for a brief period only, according to a different system and on widely differing rations as regards the relation of roughage to concentrates or the make-up of either of these classes of feed. There is, therefore, no definite basis for comparison of economy of production. It may be said that, as a rule, cows consuming large quantities of roughage will produce good returns at the pail, and such cows will also receive large amounts of concentrated feeds in a modern dairy, where individual feeding is practiced (43) Heavy cows have, generally speaking, a capacity for consuming larger amounts of roughage than small cows, but no definite relation has been established between the different breeds as regards economical use of food in the production of milk, other than that conditioned by the difference in the weights of the animals. So far as our present knowledge goes, economical utilization of food materials for dairy production is a characteristic of individual cows, and cannot be considered a breed characteristic.

DIFFERENCES IN UTILIZATION OF FOOD BY DAIRY COWS.

Illinois Experiments. A good example of the difference in the productive capacity and food requirements of different dairy cows is furnished by Fraser (45). The production and food consumption of two cows, Rose and Nora, for one full year is given in the bulletin. The former cow was credited with an average yield for the year of 31.1 lbs. of milk and 1.54 lbs. of butter fat per day on a ration containing 27.12 lbs. dry matter, 3.06 lbs. digestible protein and 15.77 lbs. digestible carbohydrates and fat (estimated from standard tables of digestibility of feeds.) The other cow, on a ration only slightly smaller, produced an average yield of 21.1 lbs. of milk and .81 lb. fat per day for the year. According to a private communicaton, the average live weights of the cows for the year were 1225 and 1125 lbs. If similar calculations are made as in the preceding, we have the following results.

Differences in Utilization of Food by two Cows.

	ROSE.			NORA.		
	Net dry matter.	Protein.	Carbohydrates and fat.	Net dry matter.	Protein.	Carbohydrates and fat.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Net nutrients eaten..........	11.7	2.20	7.10	11.7	2.13	7.12
Per 100 lbs. milk.........	37.6	7.07	22.8	55.5	10.1	33.7
Per pound fat................	7.60	1.43	4.61	14.4	2.62	8.79

The cow Nora required about 50 per cent more dry matter and total digestible matter for the production of hundred pounds of milk, and nearly 90 per cent. more for the production of a pound of fat than did Rose. "Rose produced 1.8 lbs. of butter fat and 1.39 lbs. milk for every pound of fat or milk given by Nora on the same feed and with no more body gain." A comparison of the figures given in the table with the average data for our Wisconsin herd shows that Rose required considerably less of dry matter and digestible carbohydrates and fat for the production of hundred pounds of milk than was the case on the average in our herd, while she used more digestible protein, and the various figures for Nora are in all cases in excess of those found with our herd.

Connecticut (Storrs) Results. Another illustration of the difference in the economy of production by dairy cows is furnished by Beach (46). Two cows, one Jersey (No. 27) and one Ayrshire (No. 37) in the same period of lactation and making only slight gains in live weight were under observation for six months. They were supplied with 33279 and 29447 Calories of available energy in their feed rations, in the case of Nos. 27 and 37, respectively, and the energy of the milk solids which they produced was 9998 and 5877 Calories; by deducting the maintenance needs of the cows (9585 and 10009 Calories, respectively) we find a balance of energy not accounted for of 13706 and 13561 Cal., which represents the energy that is to be charged to the work of milk formation by the two cows; i. e., with practically the same amount of energy charged to this work one animal produced 4111 Calories, or 70 per cent, more in energy of milk solids than the other.*

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*A striking illustration of differences in the economical use of food by different dairy cows is furnished by Farrington in *Hoard's Dairyman* for November 25th, 1904. The amounts of food eaten and the production by the best and the poorest cow of the four breeds entered on the

If we may accept the results given in the preceding table as typical, the question naturally presents itself, why these differences in the requirements for the production of similar quantities of milk or butter fat? As regards the nutrient requirements per hundred pounds of milk produced, the difference is, in part, explained by the difference in the average quality of the milk produced by the cows of the different groups, as will be presently shown. But this does not explain the whole difference, and with our present limited knowledge of the factors determining the secretion of milk by dairy cows, no full and adequate explanation can be offered. It is doubtless a fact that the energy required for the work of milk secretion differs in the case of different animals, and that there is an intimate relation between the nervous organism of the cows and their ability to transform the digested food more or less economically into milk solids. It is so much the more to be regretted that modern physiology has failed to shed sufficient light on this subject, as it is apparently a most potent factor in determining whether a cow is a profitable dairy animal or not.

II. EFFECT OF QUALITY OF MILK ON FOOD REQUIREMENTS.

It has long been recognized that a unit of milk containing a high percentage of fat, and therefore also of a high content of total solids, must call for a greater expenditure of energy and consequently heavier use of food materials than milk of a low fat content and low in solids. So far as is known, Haecker first gave numerical expression to this

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Dairy Test at the St. Louis Exposition are given; by placing the various figures for the best cow of each breed = 100, the data given below are obtained.

Relative Production and Feed Consumption, Dairy Tests, St. Louis Exposition.

	Brown Swiss (5 Cows).		Holstein (15 Cows).		Jersey (25 Cows).		Shorthorn (29 Cows).	
	Best.	Poorest.	Best.	Poorest.	Best.	Poorest.	Best	Poorest.
Milk production	100	75	100	70	100	80	100	50
Fat production	100	84	100	64	100	69	100	49
Coarse feed	100	103	100	111	100	78	100	97
Grain feed	100	92	100	87	100	99	100	97
Total feed	100	100.3	100	104	100	83	100	97

Similar results were obtained in the breed tests at the Columbian Exposition, Chicago, 1893 (see Armsby, *Jersey Bull.*. Dec. 23, 1896): av. of 4 lowest producers of butter fat, 51 per cent of the yield of the eight highest producers, while the cost of the feed of the former cows was 80 per cent of the feed cost for the latter cows.

difference, as has already been stated (see page 8). Since the data upon which Haecker based his deductions were obtained with only two cows, one giving 2.5 per cent milk and the other 5.5 per cent milk, no general conclusions can, however, be safely drawn from these results. The writer therefore made similar calculations of the data obtained with our University dairy herd, with a view of ascertaining the relation between the average quality of the milk produced by the cows and the net nutrients consumed by them. The following table presents a summary of the results of these calculations. The cows were first separated into six groups of five or six cows each, according to the average quality of the milk produced, and these groups were later combined so as to form three and two groups, in order that the relation in view might be brought out more strongly.

Relation of quality of milk to food requirements.

Cows Separated into		Av. Production per Day.			Net Nutr. per 100 lbs. Milk, lbs.			Net Nutrients per 1 lb. Fat, lbs.				Ave. live weight.
		Milk.	Fat.	Fat.	Net dry matter.	Dig. protein.	Dig. carbh. and fat.	Net dry matter.	Dig. protein.	Dig. carbh. and fat.	Total digest. matter.	
		Lbs.	Lbs	P. ct								Lbs.
A. 6 groups.....	1	29.9	1.03	3.44	41.2	4.35	22.3	11.9	1.26	6.46	7.72	1,147
	2	26.2	1.00	3.80	40.0	4.30	25.4	10.2	1.14	6.71	7.85	1,109
	3	23.2	.98	4.22	47.7	4.94	30.3	11.3	1.17	7.18	8.35	1,178
	4	24.1	1.16	4.81	48.9	4.90	30.5	10.2	1.02	6.32	7.34	917
	5	17.2	.91	5.29	56.0	5.80	33.3	10.5	1.08	6.27	7.35	963
	6	17.2	1.01	5.87	60.7	6.15	37.6	10.3	1.05	6.31	7.36	848
B. 3 groups.....	1	28.2	1.01	3.55	40.7	4.33	23.7	11.1	1.21	6.57	7.78	1,130
	2	23.6	1.06	4.49	48.3	4.92	30.4	10.8	1.10	6.79	7.89	1,059
	3	17.2	.96	5.59	58.1	5.96	35.3	10.4	1.06	6.29	7.35	911
C. 2 groups.....	1	26.4	1.00	3.79	43.1	4.48	26.0	11.2	1.19	6.79	7.98	1,147
	2	19.4	1.02	5.26	55.2	5.63	33.8	10.3	1.05	6.30	7.35	913
Diff. bet. 1 & 6 (A)..		.. .	.....	2.43	+19.5	+1.80	+15.3	−1.6	−.21	−.15	−.36	−299
Per 100 lbs milk & .1 per cent fat..		.....	.....	.....	+ *.81*	+*.076*	+*.638*	−*.067*	−*.0088*	−*.0063*	−*.015*	.....
Diff. bet. 1 & 3 (B)..		.....	.....	2.04	+17.4	+1.63	+11.6	−.7	−.15	−.28	−.43	−219
Per 100 lbs. milk & .1 per cent fat..		.....	.....	....	+ *.85*	+ *.08*	+ *.57*	−*.034*	−*.007*	−*.012*	−*.019*	.....
Diff. bet. 1 & 2 (C)..		.....	.....	1.47	+12.1	+1.15	+ 7.8	−.9	−.14	−.49	−.63	−234
Per 100 lbs. milk & .1 per cent fat..		.....	.....	.....	+ *.82*	+*.077*	+ *.52*	−*.06*	−*.009*	−*.03*	−*.039*	.....

We notice a marked increase in the net nutrient requirements for the production of 100 lbs. of milk with milk of higher fat contents. In group I, with an average of 3.44 per cent fat (3.47 perct., arithmetic means), one hundred pounds of milk were produced from 41.2 lbs. of dry matter, 4.35 lbs. digestible protein and 22.3 lbs. digestible carbohydrates or fat in the productive portion of the ration, against 60.7 lbs.

dry matter, 6.15 lbs. digestible protein and 37.6 lbs. digestible carbohydrates and fat in case of group VI, with an average per cent of 5.87 (arithmetric means, 5.85 perct.) fat in the milk. A comparison of the data for groups I and VI will show that for every .1 per cent increase in the fat content of the milk there was an increase in the net nutrients required for the production of a hundred pounds of milk as follows: Dry matter .81 lb., digestible protein .075 lb., digestible carbohydrates and fat, .638 lb. The corresponding figures for mature cows obtained by Haecker was .07 lbs of digestible protein and .39 lbs. digestible carbohydrates and fat (13).

When, on the other hand, we examine the amounts of food required for the production of one pound of fat, we find that there is on the average, a gradual, slow decrease in the amount of dry matter and food components as the milk becomes richer; this is especially marked when the cows are separated into three groups according to the average fat content of the milk, with eleven cows in each group. The group producing milk of the lowest per cent fat, 3.55, used 11.1 lbs. of dry matter in the productive portion of the ration per pound of butter fat, against 10.8 lbs. for the next group, with an average fat content of 4.49 per cent, and 10.4 lbs. for the last group with an average fat content of 5.59 per cent. This result suggests that cows producing rich milk are the more economical producers of butter fat, since the production of the fat is accompanied by smaller amounts of non-fatty solids. Similar differences as before referred to in case of dry matter, are found with digestible protein and other digestible components of the ration, with an exception in the second group for carbohydrates and fat which is higher than the amounts required for the first group.

Fig. 2 illustrates graphically the relation between the quality of the milk produced by cows and the dry matter required for unit of milk and butter fat.

III. EFFECT OF PERIOD OF LACTATION.

The normal change of the milk secretion as the lactation period advances is well-known and has already been referred to in the preceding. It has been noted, in general, that the amount of feed which a dairy cow consumes at different stages of the lactation period does not vary greatly, the main difference being that the amounts of grain feeds *(concentrates)* are usually reduced a few pounds when the flow of milk has been greatly diminished, and when the cow has been dried off, the grain is, as a rule, taken away in the ordinary feed practice in this country, except perhaps for a couple of pounds of wheat bran daily. It follows therefore that the food consumption per unit of milk or fat produced by the cows toward the end of their lactation periods

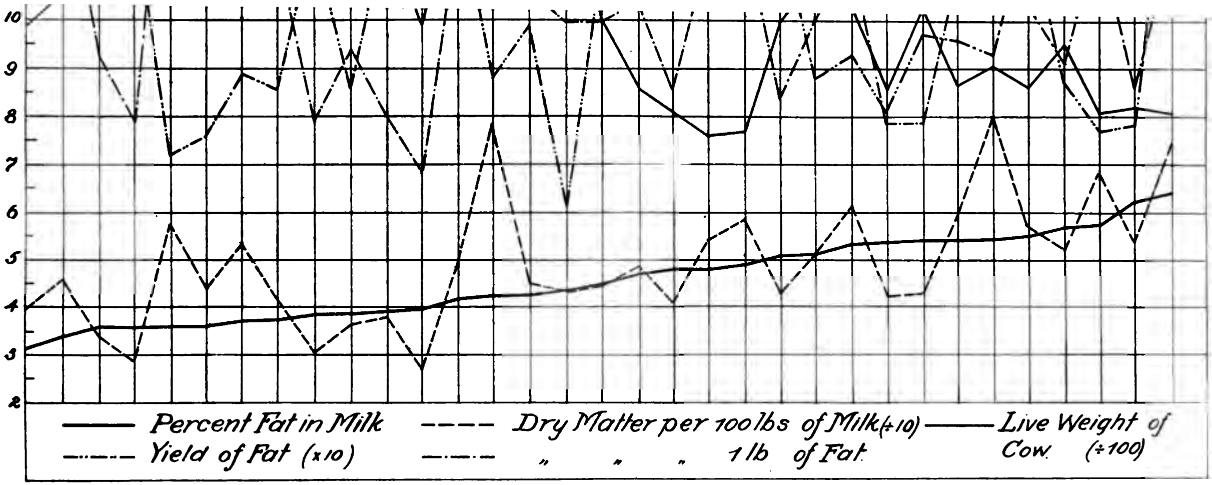

FIG. 2.—Relation between the quality of milk produced by cows and the dry matter per unit of milk and butter fat, yield of butter fat, and weights of cows. The amount of food required per unit of milk increases, and that required per unit of fat, in general, decreases slightly with the richness of the milk produced by the cows.

must be considerably greater than at the beginning of the periods. Exact data on this point are very scarce in our agricultural literature on account of the vast amount of labor involved in such calculations and the voluminous records which they necessitate. We are, however, able to refer on this point to the extensive investigation of different breeds of dairy cows carried on at the Geneva (New York) Experiment Station for four lactation periods, the data for the first two periods being especially complete. The accounts of the large amount of work laid down in this investigation, which are published in the tenth to thirteenth reports of that Station, furnish a basis for the calculation of the amount of food required for the production of a unit of milk and butter fat during the various months of the lactation period.

The data published in the 10th and 11th reports give complete records for the first two lactation periods of fourteen cows belonging to six different breeds. The first lactation extends over 16 months in case of a number of the cows, but only the first 12 months will be considered here, since the number of cows included beyond that month is too small to render comparisons with the averages of earlier months of any value. The original report gives the actual yields of milk and butter fat produced during successive months of the period of lactation of the cows included on the experiment, with the consumption of different food components for each month; from these data the average results presented in the following tables have been calculated.

Effect of lactation period on production and food consumption.

MONTH OF LACTATION.	FIRST LACTATION PERIOD.							SECOND LACTATION PERIOD.						
	Milk.	Fat.	Fat.	Dry matter.	Dry Matter per			Milk.	Fat.	Fat.	Dry matter.	Dry Matter per		
					100 lbs. milk.	1 lb. solids.	1 lb. fat.					100 lbs. milk.	1 lb. solids.	1 lb. fat.
	Lbs	Lbs.	P ct.	Lbs.	Lbs	Lbs.	Lbs.	Lbs.	Lbs.	P ct.	Lbs.	Lbs.	Lbs	Lbs.
First	13.6	.678	4.86	11.62	85.4	6.0	17.2	25.1	.979	4.02	23.6	93.9	7.1	24.1
Second	18.9	.777	4.13	19.75	104	8.0	25.4	26.0	.945	3.74	27.0	104	8.2	28.6
Third	19.5	.793	4.07	22.13	113	8.7	27.9	23.8	.840	3.71	28.9	122	9.5	34.4
Fourth	17.7	.731	4.22	23.09	131	9.9	31.5	21.2	.790	3.84	29.0	137	10.5	36.8
Fifth.........	18.0	.753	4.23	24.32	135	10.1	32.3	19.6	.726	3.87	28.5	146	11.1	39.3
Sixth.........	16.8	.716	4.35	24.70	147	10.7	34.5	19.8	.745	3.90	29.3	148	11.2	39.4
Seventh.	16.5	.691	4.39	24.05	146	10.6	31.8	19.0	.717	3.94	28.5	150	11.2	39.7
Eighth	15.7	.674	4.39	23.95	153	11.0	35.5	16.0	.603	3.89	28.0	175	13.0	46.5
Ninth	15.2	.672	4.51	24.16	159	11.3	36.0	12.5	.480	3.92	28.0	224	16.1	58.3
Tenth	14.0	.624	4.46	24.40	175	12.1	39.1	9.4	.406	4.19	26.5	282	19.4	65.3
Eleventh.....	13.4	.591	4.41	24.10	180	12.7	40.8	5.6	.255	4.58	24.3	436	28.1	95.5
Twelfth	14.3	.602	4.37	24.99	175	12.3	41.4	.....	.....	.....	.. .	.....	.....	.....

The diagrams 3 and 4 tend to bring out more clearly the variations in the figures for the production and food requirements of the cows during the different months of the lactation periods. It should be remembered in comparing these results that all the cows included in

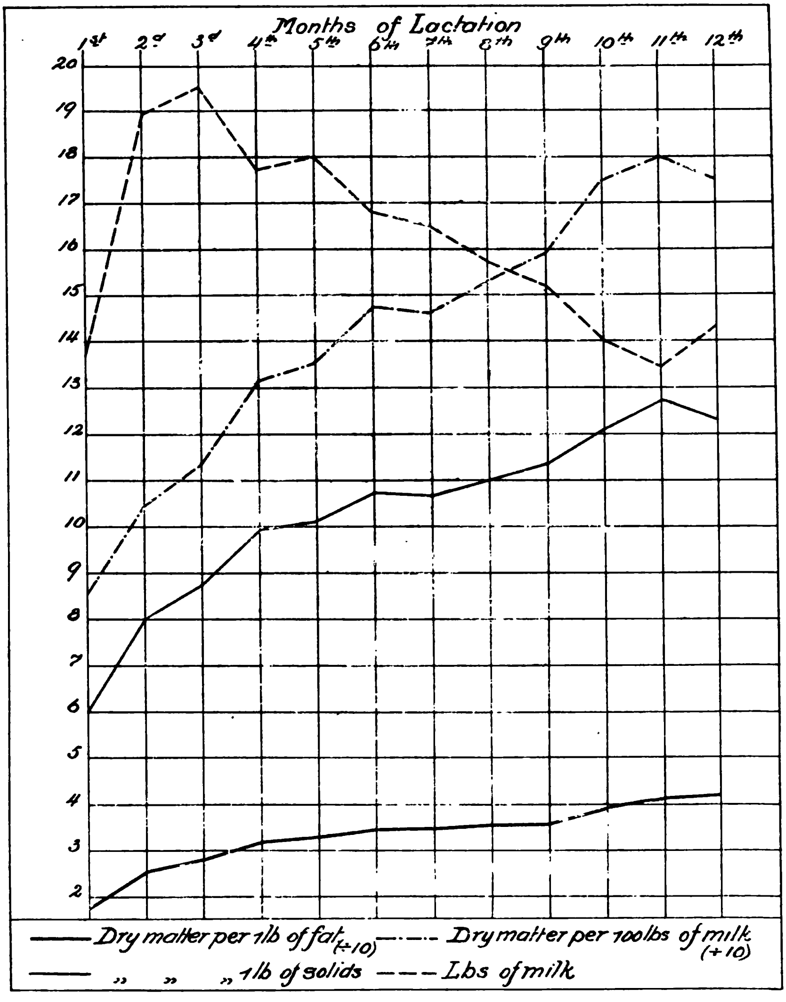

FIG. 3.—Influence of stage of lactation period on economy of dairy production. (Results obtained in breed tests at Geneva (N. Y.) Experiment Station, 1892–1893).

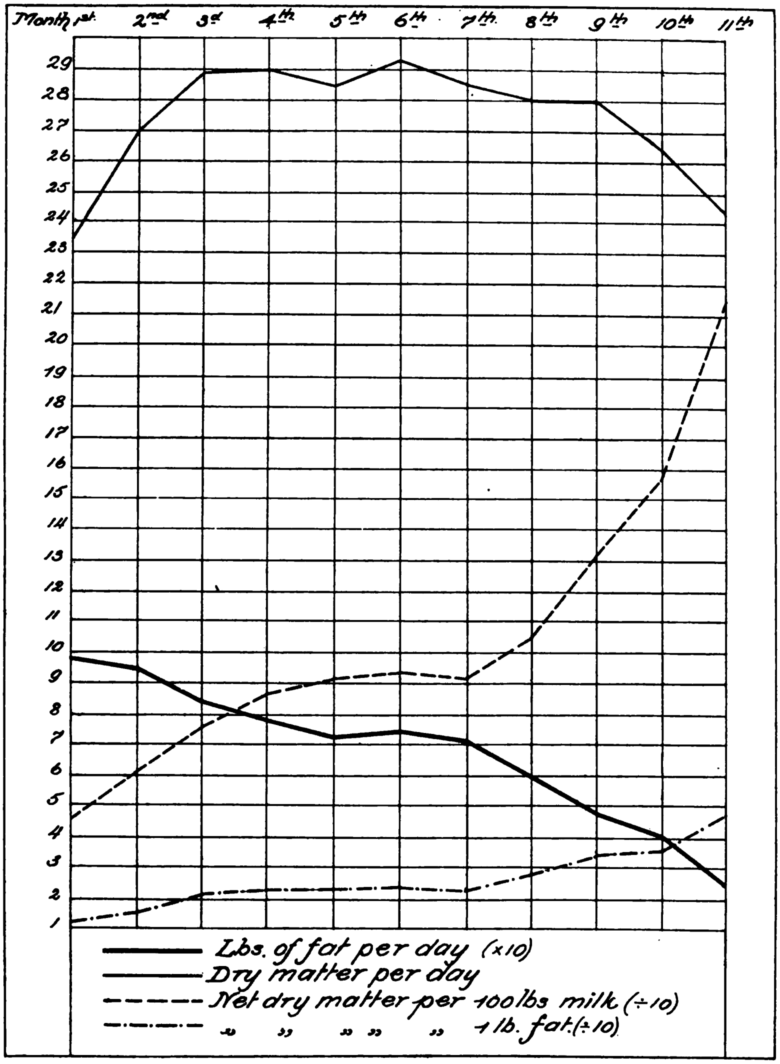

FIG. 4.—Influence of stage of lactation period on economy of dairy production. (Results obtained in breed tests at Geneva (N. Y.) Experiment Station, 1893–1894.)

the first year's record were heifers with their first calves and that the food was used for the production of milk and for increase in live weight, amounting to about 100 lbs. a head, on the average, or about ⅓ lb. per head per day; a similar increase in weight took place during the second year, but the average weight of the cows during this year was 86 lbs. above that of the first year. We have, therefore, in the preceding table the nutrients required for milk production plus an increase, in live weight as might be found in any young dairy herd where the cows were kept in milk for a similar length of time.

The fact to be especially noticed here is the increase in the dry matter required for the production of a unit of milk and butter fat with the advance of the lactation period. We note that during the first year there is an increase of from 100 to 205 in the dry matter per hundred pounds of milk between the first and the tenth month of the lactation period, a similar increase of from 100 to 227 per each pound of butter fat produced, and from 100 to 201 for each pound of total solids. During the second year when the average length of the lactation period of the cows was about normal, viz., about ten months, the increase in dry matter required for the production of a hundred pounds of milk from calving to the tenth month stood in the ratio of 100:300; for each pound of fat, in the ratio 100:271; for each pound of milk solids 100:274. That is, it took almost three times as much food toward the end of the lactation period, as at its beginning for the production of a unit of milk or milk components.

If calculations are made on basis of a maintenance requirement of 12.5 lbs. dry matter per 1,000 lbs. of live weight, we may form a fairly accurate idea as to the amounts of net nutrients required per unit of milk and butter fat produced by the cows during their first two lactation periods. The results of such calculations are shown in the following table.

Food requirements per unit of production.

	MONTH OF LACTATION PERIOD.											
	1	2	3	4	5	6	7	8	9	10	11	12
First lactation period:												
Av. weight of cows, lbs.	916	775	757	770	777	794	806	816	835	857	867	884
Net dry matter, lbs.....	2	10.0	12.6	13.5	14.6	14.8	14.6	13.8	13.8	13.7	13.3	13.9
per 100 lbs. milk......	.....	52.9	64.6	76.3	81.1	88.1	88.4	87.9	90.8	97.9	99.3	97.2
per 1 lb. fat...........	.....	12.9	15.9	18.5	19.4	20.4	21.1	20.5	20.5	22.0	22.5	23.1
Second lactation period:												
Av. weight of cows, lbs.	960	876	866	851	856	862	876	893	925	934	972	.....
Net dry matter, lbs.....	11.6	16.0	18.1	18.4	17.8	18.5	17.5	16.8	16.4	14.8	12.1	.....
per 100 lbs. milk......	46.2	61.5	76.1	86.8	90.8	93.4	92.1	105	131	157	216	.....
per 1 lb. fat...........	11.8	16.9	21.5	23.3	24.5	24.8	24.4	27.9	34.2	36.5	47.5	.....

In the preparation of this table, as in the case of similar sets of computations given before, we have taken it for granted that the maintenance requirements of dairy cows is a direct function of their body weight and that all variations as regards the efficiency of the food will therefore show itself in the productive portion of the ration. The limited amount of experimental data at hand as to the maintenance requirements of farm animals makes it impossible to furnish absolute proof for the correctness of this assumption, but we are justified in concluding that it is at least essentially correct. The food required for maintenance purposes in case of different farm animals has been determined with considerable certainty by a number of investigators during the past half century, and the available data show that the amounts of food materials required for maintaining different classes of farm animals are dependent on several factors besides the weight of the animals, as the character of the feed ration, the temperature of the surrounding air, etc. It is impossible to determine, however, from the results so far made public, the exact relation between the food for maintenance requirements and the body weight of the animals, although the subject has received considerable attention by recent investigators, especially Rubner, Kellner and Armsby. Since the maintenance food serves the purpose of carrying on the internal work of the body of the animals and repairing the waste of the body tissues, we may assume that it is a function of either body weight or body surface of the animals; in the latter case, of approximately two-thirds of the live weight. For farm animals which pass a considerable portion of their time in a standing position the former method of calculation seems preferable and has been adopted by the writer. While thus ignoring possible individual differences in the maintenance requirements of animals aside from differences in live weight or of differences in the same animals under changed conditions, for instance, at different stages of the lactation period, we do not desire to imply that this is considered absolutely correct, but it is doubtless sufficiently so to render the results obtained by this reasoning substantially trustworthy.

Support for the correctness of this view is found in the fact that the amount of food which will maintain, for instance, a dry cow at a uniform weight is fairly constant and in no way subject to such variations as are found in the food required for production in case of different individuals. If a curve showing the total dry matter consumed per unit of milk or butter fat produced for the different months of the lactation period had been platted on diagram 4, it would be seen that these run essentially similar; that is, the productive capacities of the total and the available net food increase in about the same manner from month to month, and there must therefore have been a fairly constant difference for the various months, which represents the maintenance requirements of the animals.

We find similar evidence as to the increase in nutrients required for the production of a unit of butter fat during the progress of the lactation period in Bulletin 79 of the Minnesota Experiment Station, which has already been referred to, in a chapter on "Influence of stage of lactation on nutrient requirements." In this bulletin Haecker gives the production and feed consumption during successive weeks of the lactation periods of eight cows and also a summary for 15 cows during the first nine lactation weeks, which is here reproduced. The total net nutriment is equivalent to total digestible matter furnished in the food over and above that required for maintenance.

Food requirements during the early part of the lactation.

LACTATION WEEKS.	Av. weight of cows.	Butter fat, daily.	NET NUTRIMENT PER POUND.	
			Butter fat.	Milk solids.
	Lbs.	Lbs.	Lbs.	Lbs.
First	966	1.083	3.24	.92
Second	917	1.369	3.60	1.13
Third	900	1.325	4.24	1.35
Fourth	877	1.295	4.71	1.51
Fifth	873	1.259	5.38	1.63
Sixth	863	1.232	6.07	1.72
Seventh	865	1.202	6.18	1.75
Eighth	858	1.159	6.24	1.81
Ninth	853	1.120	6.25	1.89

Numerous examples might be quoted from reports of different feeding experiments that have been published, showing that the food consumed by cows per unit of milk and butter fat is higher during later stages of the lactation period than at its beginning. Suffice it to refer to only a couple of other instances. In a feeding experiment with eight cows conducted by Wilson (Iowa Bulletin 32) the cows consumed 81.1 lbs. and 20.51 lbs. of dry matter per hundred pounds of milk and pound of butter fat, respectively, during the first period (Jan. 1–10), and 92.6 and 24.45 lbs. during the fourth period (Mar. 10–18); during the last period of the experiment (Apr. 24–May 3), 102.2 lbs. per hundred pounds of milk and 32.5 lbs. per pound of fat for four of the cows receiving dry feed during this period, and 113.1 lbs. and 29.24 lbs. per hundred pounds of milk and per pound of butter fat, respectively, for four cows on wet feed during this period.

The experiments conducted by Hayward on the influence of the nutritive ratio upon the economy of milk and butter production (47), which were continued for three years, likewise furnish testimony in this direction. Each of these experiments was conducted with ten animals and lasted from five to six months. During the first period of Experiment No. 1 the amounts of protein required for the production of one pound of milk and one pound of butter fat were .13 and 2.35 lbs., respectively, on the average for all cows, and for the last period .19 and 3.81 lbs. for milk and fat, respectively. The corresponding figures for the first period of Experiment No. 2 were .13 and 2.76 pounds, and for the last period .18 and 3.62 pounds; while for the third experiment the figures for the first period were .09 and 1.88 pounds, and for the last period .14 and 2.81 pounds. The amounts of protein required for the production of one pound of solids not fat during the different experiments in the same way ranged as follows, from the first to the last periods in each case.

Experiment 1. 1.54 to 2.18 lbs. digestible protein per lb. solids not fat produced.
Experiment 2. 1.47 to 2.00 lbs. digestible protein per lb. solids not fat produced.
Experiment 3. 1.00 to 1.58 lbs. digestible protein per lb. solids not fat produced.

By a recalculation of the data published in Bulletin 65 of the New Jersey Experiment Station, Experiments with different breeds of dairy cows, it is found that the amounts of digestible matter in the rations fed required for the production of hundred pounds of milk were as follows during the different feeding periods, on the average for all cows of the five breeds included on the experiments: August 55.9 lbs., September 41.4 lbs., October 47.3 lbs., November 80.1 lbs., December 83.3 lbs., and January 94.1 lbs.*

The most economical dairy production so far as the relation of food consumption to production is concerned, therefore, comes during the first months of the lactation period; with the advance of the period a larger proportion of food materials is required; i. e., the feed consumption does not decrease with the production of the cows, whether the production of milk alone be considered or this in connection with the increase in weight due to the development of the foetus during the latter stages of the lactation period.

IV. INFLUENCE OF AGE OF COWS ON ECONOMY OF PRODUCTION.

In considering the influence of the age of cows on the economy of production of milk and butter fat we differentiate between heifers and older cows. It is to be expected that in case of young animals which use the energy of the digested food in two directions, for increase in body weight as well as for producing milk, a considerably larger amount of food materials will be required for the production of a unit of milk and butter fat than with animals that have reached their full bodily development. It is not surprising, therefore, to find that the two-year old heifers in our University herd were not as economical producers of dairy products as during the following year. The table below presents the results on this point that are obtained from our records for the past five years.

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*See also data published by Thorne, Ohio Bulletin No. 50, Nov., 1893, p. 76; Henry, "Feeds and Feeding," p. 407.

Production and food consumption of heifers.

AGE OF COWS.	Milk, per day.	Per cent fat.	NET NUTRIENTS PER 100 LBS. MILK.			NET NUTRIENTS PER 1 LB. FAT.			Average weight of cows.	Number of animals.
			Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. carbh. and fat.		
	Lbs.								Lbs.	
Two years old	22.6	4.16	67.9	7.04	41.4	16.5	1.73	9.95	943	4
Three years old...........	28.3	3.93	35.5	3.41	21.2	9.2	.90	5.46	1,005	4
General average for herd	23.1	4.37	49.0	5.07	29.8	10.8	1.12	6.55	1,033	33

It has been shown by Professor Carlyle and the writer that the quality of the milk of cows is, in general, lowered somewhat with the advancing age of cows (48).* We find this to be the case, on the average, with the cows included in the preceding table, and we should therefore expect that under otherwise similar conditions a larger amount of net nutrients would be required for the production of milk and butter fat in case of the two-year olds than during the third year. A correction for the difference in the average quality of the milk produced during the two years would, however, only reduce the difference in dry matter in the productive portion of the ration by 1.6 lbs. per hundred pounds of milk and .12 lbs. per one pound of fat, leaving a difference of 30.8 lbs. and 7.18 lbs. per hundred pounds milk and one pound of fat, respectively.

If the data for cows that have been in our University herd for two winter periods or more be arranged according to the number of years of the cows in our herd, we arrive at the results presented in the statement given below.

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*See also Humphrey & Woll, Report 21 of this Station, pp. 102–3; LaCour, Exp. Sta. Record, 6, 456; Hittcner, Ldw. Jahrb., 28, Erg. III, p. 349; Hittcher, Milchviehzucht auf Leistung, Berlin, 1899, p. 32; Speir, Milk Records, Trans. Highl. & Agr. Soc. Scotl., 1904, 17.

Influence of age on production and food consumption.

YEAR AT UNIVERSITY FARM.	No. of cows.	Average age.	Average weight	NET NUTRIENTS PER 100 POUNDS MILK.			NET NUTRIENTS PER 1 POUND FAT.		
				Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. carbh. and fat.
		Yrs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
First	26	4.5	1,021	59.3	6.07	37.2	13.0	1.34	8.16
Second	26	5.5	1,043	41.6	4.46	26.3	9.4	1.00	5.88
Third	15	6.6	1,093	40.5	4.41	26.8	9.5	1.06	6.38
Fourth	10	7.6	1,057	45.5	4.90	27.6	10.5	1.13	6.38
Fifth	4	9.5	1,116	39.9	3.65	18.7	6.9	.85	4.29
Gen. av. for herd	*33*	*5.7*	*1,033*	*49.0*	*5.07*	*29.8*	*10.8*	*1.12*	*6.55*

The data given in this table are corroborated by the results of computations along this line made by Thorne (25).

The figures shown below have been obtained by recalculations of the data presented in the bulletin referred to, for the purpose of ready comparison with the results previously given. In the second column of the table the dry matter consumed for every pound of butter fat and gain in live weight is given, on the supposition that three pounds of increase in weight will require a similar expenditure of energy and approximately the same food consumption as the production of one pound of butter fat; the author shows in the bulletin mentioned that this relation holds true.

Effect of age of cows on the productivity of feed.

Age of cows.	No. of cows included.	Dry matter per lb. butter fat and increased weight.	Dry matter per butter fat produced.
		Lbs.	Lbs.
3- 4 years	7	29.4	33.9
5 years	7	30.3	33.4
6 years	10	26.1	29.0
7 years	6	28.8	27.6
8 years	4	28.4	31.8
9 years	5	34.1	32.8
10 years	6	32.3	31.1
11-13 years	2	39.2	36.4

The following conclusions are considered justified by the results given in the preceding: Young animals require a larger proportion of net nutrients for the production of a unit of milk and fat than do older cows; after a certain age has been reached, say above seven years old, the food required for milk production again increases both as regards dry matter and digestible components in the food. The very favorable results obtained during the fifth season for the cows that had been in our herd for this length of time, are in all probability accounted for by the small number of cows included in this group, viz., four cows (Maud, Pauline, Ella and Bessie), all of which were among the most economical producers in the herd.

We thus see that there is a period of optimum conditions as regards economic production of milk and butter fat in the life of the dairy cow, as there is within each lactation period. This period seems to come after the cow has reached her full-age form and will ordinarily last only a few years. A cow may continue a heavy producer after this time and a very economical one, but quite as good returns as before per unit of food eaten are not likely to be obtained. Since feed is relatively cheap, it does not follow, however, that a relatively less economical production may not still be a profitable one.

V. THE EFFECT OF THE CHARACTER AND AMOUNT OF THE FEED RATION.

INFLUENCE OF THE INTENSITY OF THE SYSTEM OF FEEDING.

The character of the feed ration is of importance in determining the economy of the production both as regards its composition and the quantity fed. The question whether a heavy ration is as effective and economical as a medium or small ration is answered by experiments conducted during two successive years by Carlyle and the writer (49), by experiments conducted during three successive years by Hills of Vermont Experiment Station (50), and by other experiments, the accounts of which are scattered throughout our agricultural literature.

Wisconsin Experiments. In the first Wisconsin experiment with 12 cows, conducted in 1899, it took 129 lbs. of dry matter per hundred pounds of milk, in the ration containing 8 lbs. of grain (2 lbs. each of ground corn and oats, 3 lbs. of wheat bran and one pound of oil meal), against 143 lbs. when the grain rations were increased by 50 per cent, the dry matter required per pound of butter fat being 25.9 and 28.8 on normal and heavy grain rations, respectively.

In the second year's experiment with 16 cows, a similar increase of 50 per cent in the amount of grain fed (which varied from 4 to 10 pounds per day and per head, in the case of individual cows) during period II of the experiment resulted in a small gain in the production of milk and butter fat, but the increase was obtained at a financial loss at ordinary Western market prices for feed. On the heavy grain rations the cows consumed 86.2 to 116 lbs. of dry matter per hundred lbs. of milk (average, 100.7), and 18.5 to 33.3 lbs. of dry matter per pound of fat (average, 23.8), the corresponding figures for the normal grain ration being 80 to 111 lbs. (average, 91.8) per hundred lbs. of milk and 16.4 to 28.6 lbs. (average, 21.7) per pound of fat; all the cows in the lot fed the heavy grain ration consumed more dry matter per unit of milk and butter fat during the heavy grain period than during the average of the normal grain periods.

Nor did the heavy grain feeding tend to maintain the milk or fat production of the cows better during the two months following the experiment than did the normal grain feeding. On the contrary, the after-effects were decidedly in favor of the normal grain-feeding, in all probability due to the digestive system of the cows being overtaxed during the period of heavy grain-feeding. The conclusion is drawn from the results of these experiments "that it does not pay to feed dairy cows more than a medium amount of grain feed, which may be placed at about 8 lbs. per head daily, except in case of cows of marked dairy tendencies that respond to heavy grain feeding by an increased production of milk and butter fat, rather than by a gain in live weight."

Vermont Experiments. Experiments were conducted along similar lines during three successive years, 1899–1902, at the Vermont Experiment Station, as stated above, in which the effects of low, medium and high grain rations fed to 24 cows were compared with each other, viz., 4, 8 and 12 lbs. per head daily. The following summarry shows the financial aspect of the case.

Relative value of low, medium and high feeding.

	Medium better than low ration.	High better than medium ration.
Days of feeding on each ration	342	378
Cost of added grain feed	$13.85	$11.96
Net gain from butter sales at 20c	$7.86	$1.12
Net loss, i. e., cost of additional grain less value of butter	$5.99	$10.84
Value of skim milk and of two-thirds of the manurial ingredients	$6.25	$4.70
Net gain (or loss) from butter, skim milk, and manure	$0 26 gain	$6.14 loss
Net gain (or loss) from one day's feeding of one cow	0.08 c gain	1.62c. loss

At no time did the increase in butter fat obtained by the feeding of the *medium* ration pay for the extra grain, over that fed on the *low* grain ration, but if the value of the butter, skim milk and enriched manure be considered there was a small margin of profit above the cost of grain. Comparing the *heavy* and *medium* grain rations, a small gain was obtained the first year and a small loss the last two years, by feeding twelve pounds of grain instead of eight pounds. "If butter returns only are considered, the losses are far greater than these figures, which represent the outcome when extra butter, skim milk and manurial values are reckoned as assets. Not only may money loss be anticipated, but bovine health may be shattered and future usefulness be lessened as a result of high-pressure feeding." Prof. Hills states as a general conclusion (51) that, when all the different factors are taken into consideration, from six to eight pounds of grain daily seem the most advisable amounts to feed to mature cows, eight in years when grain is unusually cheap and six when prices rule high. "Four pounds of grain daily does good service for four weeks, and indeed it may for four months; but will it prove equally as satisfactory for four years in regular practical every-day feeding? The writer believes that in the long run a more liberal ration would prove more satisfactory."

Experiments at Other Stations. Mention will be made in the following of a few other experiments that have a bearing on the question of the economy of high feeding. Although they have not been conducted on as large a scale or planned with that specific point in view as was the case with the Wisconsin and Vermont experiments, they still furnish valuable evidence on this point.

In experiments at the New Jersey Experiment Station several tests of one week each were made with two cows to determine the profits from feeding different quantities of mixed grains, viz., 10 to 24 lbs. fed with silage and hay (52). The conclusion is drawn that "rations containing feeds in excess of 10 lbs. per day, while they were profitable, were less profitable than those containing this amount."

Linfield experimenting with different amounts of grain in winter rations to two lots of five cows each at the Utah Experiment Station, viz., 6 to 12 lbs. during periods of 8 weeks, concludes that any increase in the grain ration over 6 lbs. per day increased the cost of dairy products almost without exception and believes that with the feeds used (alfalfa or mixed hay, with wheat and bran, equal parts by weight) 8 lbs. of grain is the highest limit for the greatest profit (53).

An investigation of the relation of milk yield and feed consumption conducted by Holtsmark during the past year furnish valuable evidence on this point (54). This author tabulated the average production and feed consumption of 846 Norwegian dairy herds during the year 1902 and by means of a logarithmic function obtained the formula for a curve showing the amount of food units required for the production of different annual milk yields. The number of food units fed to the herds is calculated by the method referred to on page 5. The results obtained agree very closely with the yields actually found in the different herds. The following table gives some of the main results of the calculations.

Influence of intensity of system of feeding.

Number of food units.	Milk yield in kilograms.	Kilograms of milk per 100 food units.	Increase in milk production per 500 food units.
1,500	923	61.5	....
2,000	1,424	71.2	501
2,500	1,813	72.5	389
3,000	2,131	71.0	318
3,500	2,399	68.5	268
4,000	2,632	65.8	233
4,500	2,837	63.1	205

The largest yield of milk per 100 food units, 1743 kilograms, was obtained by feeding 2402 food units; we notice from the data given in the last column of the table that the increase in production per 500 food units grows smaller the heavier the cows were fed, a result that fully corroborates the testimony already published on this point.

We are justified in concluding from the results of the investigations of the subject referred to in the preceding that the feeding of dairy cows on economical grounds as well as from physiological considerations can easily be too intensive; that the organism of the dairy cow responds to a liberal supply of feeding stuffs by a large production of milk, but the amounts of feed which can be fed to advantage will depend on the cost of the feed and the returns from the milk and its products. The higher the latter, or the lower the former, the more feed can profitably be fed, and *vice versa.* This relation has been brought out in a striking manner in the investigation by Holtsmark referred to above. See also Armsby (55), Winberg (56), Käppeli (57), Fr. Lehmann (58), Ramm (59).

Economy of Production by Dairy Cows of Exceptional Capacities. Some tests of three exceptionally good pure-bred Holstein cows which were conducted a few years ago at the Michigan Station furnish especially valuable data as to the economy of the production of such cows, on account of the large production of the cows, the great skill used in feeding them, the care with which the tests were conducted, and the length of the tests (60). We condense in the following table the main results obtained bearing on the point under discussion, only prefacing this with the remark that the periods covered by the trials were during the months of December to May, when the cows were on winter rations, and that the first cow was crowded with feed to her limit during the whole trial, while this was not the case to the same extent with the two other cows.

Food consumption and production of three large producers.

		Rosa Bonheur 5th.	Houwtje D.	Belle Sarcastic.
H.-F. Herd-book, No.		11277	12005	23039
Length of feeding periods, days		63	133	147
Weight of cows, lbs		1,750	1,580	1,550
Av. yield of milk per day, lbs		92.4	33.0	49.3
Av. yield of fat per day, lbs		2.66	1.42	1.57
Av. per cent. of fat in milk		2.88	4.30	3.19
Composition of rations fed:				
	Dry matter, lbs	52.65	33.75	35.89
	Dig. protein, lbs	5.25	2.92	3.22
	Dig. Carbh. + fat	31.77	20.71	21.28
	Nutr. ratio, 1:	6.1	7.1	6.6
per 1,000, lbs. live wt.	Dry matter, lbs	30.1	21.4	23.2
	Dig. protein, lbs	3.00	1.85	2.08
	Dig. carbh. + fat	18.2	13.1	13.7
Net nutrients eaten.	Net dry matter	30.77	14.00	16.51
	Dig. protein	4.02	1.81	2.13
	Dig. carbh. + fat	19.12	9.29	9.98
Net nutrients required:				
per 100 lbs. milk	Net dry matter	33.3	42.2	33.5
	Dig. protein	4.35	5.48	4.30
	Dig. carbh. + fat	20.7	28.1	20.3
per lb. fat	Net dry matter	11.7	9.9	10.5
	Dig. protein	1.51	1.27	1.36
	Dig. carbh. + fat	7.19	6.54	6.36

If a comparison be made between these results and the average data obtained with our Wisconsin herd (see page 19), we find that in case of all three cows considerably less dry matter or digestible matter was required for the production of a hundred pounds of milk, while it took about the same amounts of net nutrients for the production of one pound of fat as the average for our Wisconsin herd. Considering the much larger amounts of feed eaten by these cows, especially by Rosa Bonheur, we cannot but wonder at the efficient use which they were able to make of the food for the production of milk and butter. So far as our knowledge goes there is no authentic record published of a more economical large production of milk and butter fat by dairy cows as regards the utilization of the food consumed. Similar results would, however, doubtless be obtained on many of the so-called official dairy tests of heavy producers if the exact quantities of feed consumed on these tests and their chemical composition were known with certainty. It must be remembered, however, that these tests are of but short duration and are conducted without reference to the permanent value of the animals tested for economical dairy production.

INFLUENCE OF THE CHARACTER OF THE RATION.

The amount of feed given is only one of the factors determining the profitableness or economy of a feed ration. The character of its components and its proximate composition are of equal importance, at least up to a certain extent, as will be shown in the following pages.

The metabolic processes in the body of a milch cow are very intense; through hereditary influences of various kinds the productive capacity of the dairy cow has been greatly increased, and the requirements of cows for large quantities of easily digestible foods have been correspondingly raised.* Pasture grass is the natural food for bovines and in the winter feeding of dairy cows the farmer aims to supply feed of a similar character and nutritive value. Experience and experiments agree in showing the superior value of succulent feeds for dairy cows, like pasture (when available), soiling crops, silage, or roots (62). During the period of winter feeding the main reliance of farmers for succulent feeds must rest on the latter two feeds and, in this country, above all on silage and especially corn silage. The great value of corn silage as a food for dairy cows was established by a number of investigations during the eighties and later, among which those conducted by the writer at this Experiment Station have a special bearing on conditions in this and the northwestern states generally (63).

Among other stations the New Hampshire, Maine, New Jersey, Massachusetts, Michigan, Geneva (New York), Ohio and Vermont (64) Experiment Stations conducted feeding experiments with silage for milch cows which bring out strongly the superior value of this feed for milk production as compared with dry fodder corn or hay. The general distribution of silos in our dairy districts at the present time furnishes cogent evidence of the importance of succulent feeds and of silage in the feeding of dairy cows. The system of dairy farming has been almost revolutionized in this country during the last two decades, through the addition of the silo to the equipment of the dairy farmer.

In northern European countries and in Canada where corn does not reach the wonderful development of which it is capable in this country, roots, fodder beets, mangels and turnips are an ever-present constituent of the ration of the dairy cows. In experiments with dairy cows with dry vs. wet feed at the Iowa Experiment Station (65), Wilson shows that when no roots were fed, butter fat decreased and more pounds of dry matter were required to make a pound of butter fat and concludes that "the *lack* of roots interfered with the digestibility or assimilation." The dry matter eaten per pound of butter fat in these trials ranged between 27.9 and 32.5 for the various dry feed periods and between 24.9 and 29.2 for the wet feed periods. This is in conformity with the teachings of modern physiology as regards the relative amounts of energy required for mastication of green and dry fodder; the more succulent the fodder the higher its value per pound of dry matter, because of the increased amount of energy required to masticate dry fodders. According to Zuntz, if it requires 47 units of energy to masticate a fodder when green, it will require 76 units to masticate it after it is dried (66); thirty-eight per cent of the work of mastication is therefore saved in the case of the green feed. It should be remembered in this connection that the figures given cannot be taken to represent the relative value of corresponding amounts of green and dry fodders, for the reason that mastication is only one of the processes calling for the expenditure of energy in the digestion of food materials.

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*The difference in the metabolism and production of the dairy cow and the fattening steer has been pointed out by Lawes and Gilbert in their paper on the Feeding for Milk Production (61).

Aside from the desirability of rations of dairy cows containing some succulent feed, the chemical composition of the food materials contained therein is of considerable importance; in other words, the nutritive ratio of the rations and the amounts of digestible protein which they supply. A consideration of the importance of the nutritive ratio in feeding dairy cows is intimately connected with another question, viz., the influence of the food on the composition of the milk, especially as regards its content of fat.

INFLUENCE OF FOOD ON THE FAT CONTENT OF MILK.

Around the question of the influence of the food on the composition, and especially on the fat content of the milk, a whole literature of experimental evidence has arisen since the latter part of the sixties of last century, and many efforts have been made to show that the character of the milk secretion can be changed at will by the feeding of certain food materials or by feeding rations of a certain character. In examining into the effect of the food on the milk secretion we differentiate between a possible change in

(1) the quantity of milk produced and

(2) in its quality, as regards (a) the proportion of solids in the milk and (b) the proportion of fat or any other single components of the milk solids, and

(3) in the effect as regards the flavor of the milk or milk products.

We shall not take up space discussing the influence of the food of the cow on the quantity of milk produced, as practical experience and all experiments with milch cows agree in showing that there is a direct inter-relation between the two and that an increase in the amount of food supplied a cow will increase her production of milk up to the limit determined by her dairy capacity, which is again a function of her udder development and her ability to convert the digested and assimilated food into milk secretion. This is a familiar effect which need not here be further enlarged upon; illustrations of this effect are, however, furnished by data and discussions in other places of this bulletin.

Liebig's view, that the fat in the body of animals, including the fat of milk, has its origin in the digested and assimilated nitrogenous portion of the food, would naturally lead to the inference that the fat in the milk might be increased at will by increasing the amount of protein substances in the food, or by rendering the ration relatively richer in protein; that is, by narrowing the nutritive ratio.*

The theory previously held as to the process of milk secretion might also render such a change in the character of the secretion more feasible than can now be the case, since it was believed that milk was a direct secretion from the blood and that, given large amounts of nutrients in solution in the latter, the composition of the milk would be readily improved in proportion. When this theory was shown untenable through the investigations of Fürstenberg, Voit, Virchow, Heidenhain and others (68), theoretical reasons gave less ready support to the view that the fat in milk or the other milk solids can be appreciably changed in a one-sided manner through any special system of feeding or by special feeding stuffs.

The experiments of G. Kühn with three milch cows, in which palmnut cake meal apparently caused a marked increase in the fat content of the milk produced by two of the cows and in the ratio of fat to non-fatty solids in the milk of these cows (69), were directly responsible for a vast amount of experimentation in regard to this question. Another reason for the accumulation of evidence on this point must be sought in the fact that practical experience in many cases seemed to point to a possible interrelation between the character of the ration and the quality of the milk produced by the cows. Many farmers were, and in fact are, convinced that it is possible to change the fat content of the milk by the use of special feeding stuffs or combination of feeds, and in discussions at farmers' gatherings of all kinds in the past, this view has frequently been stated and its correctness maintained. The mass of experimental evidence on this point which has accumulated during the last decade or two has, however, been generally interpreted to prove that the influence of the feeding of a highly nitrogenous feed or other systems of feeding in changing the normal quality of the milk is only insignificant; given a ration which supplies an amount of food materials sufficient to enable the cow to maintain her body weight at the same time that she is producing milk, it does not appear to be possible, by an addition of nitrogenous or non-nitrogenous components to a ration, to materially and permanently change the percent of fat in the milk produced by the cow. It is not necessary in this place to refer to all important investigations on this point that have been published, since this has already been done by a number of authors; in this country by Armsby (70), Jordan (71), Hills (72), Atwater and Phelps (73), Anderson (74), and Woods (75), besides more or less exhaustively by the various investigators who have added their contributions to our knowledge of this subject, e. g. lately by Lemmermann and Linkh (76). We shall, however, present such new or recently published testimony on this question as is now available.

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*The question of the source of the fat in the milk which for a long time was under discussion by physiologists may now be considered definitely settled by the investigations of Jordan and Jenter (67), in which experiments rations practically free from, or very low in, fat were fed to cows. On these rations the cows produced milk of a normal fat content, showing that the fat in the milk must to a large extent have been derived from the carbohydrates of the food.

Experiments on Influence of Food on Quality of Milk. In looking at the evidence that has been published as to the effect of food on the quality of milk one must bear in mind the short-comings of many of these experiments, to which attention has already been called (see page 11). A feeding experiment with one or two milch cows continued for a week, ten days or even a few weeks, according to our present knowledge, cannot be taken to furnish reliable testimony as to the specific effect of the food on the milk produced. If the criterion of a reliable cow-feeding experiment maintained by either Hills or Thorne (see page 12) be accepted, a large number of experiments published as contributions to this subject will be ruled out, and there can be little doubt in the minds of critical students but that they should be excluded from consideration, except as indicating a possible immediate effect on changes of food on the quality of milk in the case of individual cows.

The main experiments indicating that changes in feeding ration *may* alter the quality of the milk produced by the cows are reviewed by Hills in the Vermont report referred to above and include those conducted by Stohmann (1886 with two goats), G. Kühn (1886–87), Dean (1891–92), Wilson, Curtis, Patrick and Kent (1891), Fleischmann (1891), Cook and Hills (1892–1895), Jordan (1893), Lindsey (1894), and Soxhlet (1896). In many of these experiments the changes in the fat content supposed to have come as results of changes in the system of feeding are infinitessimal. In other cases, not sufficient explanation or detailed information is published by the respective authors in regard to the conditions of the experiment, to decide whether or not the evidence justified the conclusions drawn. Without going into further discussions of these experiments we may say that they led Hills to conclude that "the amount of trustworthy evidence in favor of the possibility of feeding fat into milk by normal means will be but small, if the results of the Vermont experiments as to the futility of conducting cow-feeding experiments for shorter periods than four weeks are confirmed by future work.."

We shall not here take up space with a discussion of older experiments that furnish evidence on the special subject under investigation, which have been interpreted to prove that no direct relation exists between the quality of the milk and the food when rations normal in composition and amount are fed. Suffice it to simply refer to a few of such experiments not reviewed by the writers quoted above, which incidentally give testimony as to the relation of food to quality of milk (77).

These experiments furnish no stronger evidence on the question under discussion than those commented on by Hills; they certainly show conclusively, so far as they go, that the quality of the milk is subject to changes which cannot be accounted for by the character of the rations fed to the cows. We have no explanations to offer for the large variations that often occur in the average quality of the milk produced by the cows when on the different rations, other than that they show the immediate effect of the change in rations. The food is only one of the factors that influence the quality of the milk; other factors are, besides the inbred characteristics of the animal herself, her body condition, the treatment which she receives, the interval between milkings, method of milking, coming in heat, weather, etc. (78). It will be seen these influences are all such as are apt to affect the nervous organization of the cow. They are never exactly the same at different times; hence variations in the milk secretion, which we know is intimately related to the nervous system of the cow, will occur from milking to milking and from day to day, and frequently without our being able to point to any specific cause.

The cow-feeding experiments conducted at the Copenhagen Experiment Station since the eighties, are, in a measure, different from other experiments with dairy cows. These experiments are especially important contributions to our knowledge on the subject of the influence of food on the composition of milk, on account of the large number of animals included on the experiments, the great variety of conditions under which they have been conducted, and the care and thoroughness with which the work has been done. In these experiments the relation of the food of dairy cows and their production has also been studied, although the experiments were not primarily planned with this object in view. As regards the point under discussion, the conclusion drawn from ten years' investigational work at that Station with over 2,000 cows in all is, that the changes made in the character of the feed rations of the different lots of cows included in the experiments have had no appreciable influence on the chemical composition of the milk produced (79). In these experiments grain feeds have been compared with roots as a food for dairy cows, with oil cake and with wheat bran or shorts; grain and oil cake have furthermore been fed against roots, and roots have been given as an additional feed to the standard rations tried, which were similar to those commonly fed on Danish dairy farms, in all cases with negative results so far as marked changes in the fat content of the milk produced was concerned.*

After this reference to older experiments, the results of which may be said to have been generally accepted as proof that the quality of milk is not materially influenced by the character of the rations fed, we will now consider the results of recent investigations in this line obtained at our own Experiment Station and elsewhere.

Recent Experiments at This Station. The experiments by Professor Carlyle and the writer, conducted at this Experiment Station during the years 1898–1903, which have been repeatedly referred to in the preceding, were continued during the past year by Professor Humphrey and the writer, and the results obtained during the winter period ending May 18, 1904, have just been compiled. A full account of the experiments will be found in the forthcoming twenty-first annual report of our Station (80), and it will only be necessary to state here that the system of feeding followed during this period was changed so that rations containing more protein and of a narrower nutritive ratio than those fed in previous seasons were supplied all the cows with but two exceptions. The results as regards the average quality of milk produced by the different cows that were in the herd during both periods considered, November 12, '02, to May 13, '03, and November 18, '03, to May 18, 04, are given in the following table, which also shows the average live weights of the cows during the two periods, the dry matter and the digestible protein in the average rations fed, the nutritive ratios of these rations, and the average production of milk and butter fat for each day of the two periods considered.

Since in the case of two cows, the nutritive ratios fed during 1903–04 were wider than those fed during the previous season, the average data for all cows but these two have also been calculated and are given in the last line of the table.

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*Abstracts of the various reports describing the cow-feeding experiments conducted at the Copenhagen Experiment Station will be found in *Experiment Station Record*, v. 4, p. 601; 6, pp. 588, 657; 8, p. 255; 9, p. 903; 11, p. 780.

Comparison of rations fed and production, 1902-3 and 1903-4.

No.	NAME OF COWS.	LIVE WEIGHT.		DRY MATTER.		DIG. PROTEIN.		NUTR. RATIO.		MILK PER DAY.		FAT PER DAY.		PER CENT FAT.		In-crease.
		1902-3.	1903-4.	1902-3.	1903-4.	1902-3.	1903-4.	1902-3.	1903-4.	1902-3.	1903-4.	1902-3.	1903-4.	1902-3.	1903-4.	1903-4.
		Lbs	Lbs	Lbs.	Lbs	Lbs.	Lbs	1:	1:	Lbs	Lbs.	Lbs.	Lbs.			P ct.
1	Maud	1,209	1,188	24.07	25.49	2.00	2.22	7.0	6.6	20.9	21.9	.77	.95	3.62	4.34	.74
2	Muriel	821	936	16.95	18.87	1.30	1.31	7.6	8.4	10.6	12.4	.66	.77	6.19	6.21	.02
3	Dorine	857	1,022	17.12	19.02	1.35	1.61	7.4	6.9	11.5	11.7	.61	.70	5.34	5.98	.64
4	Lady...........	1,147	1,169	31.94	26.95	2.91	2.68	6.8	5.7	39.9	36.7	1.63	1.56	4.08	4.25	.17
5	June	1,045	1,259	20.97	24.39	1.56	2.23	8.0	6.4	19.7	17.6	.74	.67	3.75	3.81	.06
6	Brownie	1,036	1,037	20.50	21.63	1.61	2.24	7.6	5.7	15.1	21.9	.81	1.28	5.33	5.84	.51
7	Joe............	1,040	1,107	27.78	26.05	2.56	2.94	6.2	5.3	38.9	41.3	1.33	1.47	3.42	3.56	.14
8	Laura........	913	955	22.70	22.98	1.99	2.16	6.8	6.0	18.3	16.1	.97	.83	5.30	5.16	.14†
9	McGeoch......	1,203	1,355	21.92	23.93	1 76	2.19	7.4	6.3	22.6	13.7	.84	.54	3.68	3.94	.26
10	Donation	1,248	1,301	23.46	23.10	1.93	2.36	7.4	5.7	28.3	28.0	1.02	1.04	3.60	3.71	.11
11	Campbell	1,225	1,211	21.47	20.77	1.60	1.65	8.0	7.4	6.4	14.5	.25	.61	3.92	4.21	.29
12	Reba	912	969	17.02	19.18	1.17	1.60	8.6	7.0	12.0	11.2	.61	.65	5.08	5.80	.72
13	Bessie..........	873	1,032	21.86	18.02	2.09	1.33	6.2	7.5	26 1	10.7	1.18	.57	4.50	5.32	.82
14	Alma...........	1,001	1,083	25.71	21.96	2.21	2.23	7.1	5.8	37.6	34.7	1.17	1.07	3.10	3.09	.01†
	Averages......	1 038	1,116	22.39	22.31	1.86	2.05	7.3*	6.5*	22.0	20.9	.90	.91	4.35	4.66	.31
	Averages (excl. of No. 2 & 13	1,070	1,137	22.89	22.95	1.89	2.18	7.0*	6.2*	22.6	22.4	.90	.95	4.18	4.47	.29

* Arithmetical means; av. dig. carbh. and fat ÷ dig. prot. for herd was 1:7.1 and 1:6.3 (excl. No. 2 and 13, 1:7.2 and 1:6.1.) † Decrease.

The main interest centers in the figures in the last column of the table which show the increase in the average percent of fat in the milk produced by the cows during the winter period 1903-04 over the corresponding figures for the preceding period. We note that there is a uniform increase in the average fat content of the milk produced by all the cows but one on the narrower ratio fed last winter, if we consider the percent of fat in Alma's milk the same for both years, as is practically the case. In the case of four cows this increase exceeded one-half of one percent and on the average for the twelve cows it amounted to .29 per cent in favor of the narrower ratios. This improvement in the average quality of the milk was accompanied by an increase in the weight of the cows amounting to 67 pounds per head, on the average, and by a falling off in milk yield of .2 pounds, so that the total production of butter fat was also increased, viz., by .05 pound per head per day. While this may seem too small to some to be worth mentioning, it is equivalent to one pound a day for a herd of 20 cows, or 300 pounds of butter fat for the year for such a herd.

It is not claimed that these results furnish conclusive evidence on the point under discussion because the cows were not kept under directly comparable conditions in all respects during the two seasons considered. The influence of differences in the age and live weights of the cows the two seasons, as well as the uneven milking periods of some of the cows, should be considered in interpreting the results; it may be said, however, that on the whole, the points of differences are such as would tend to affect the fat content of the milk in the opposite direction of that noted, and we feel warranted, therefore, in taking the results on their face value and concluding that the teachings of these are what they appear to be.

The diagram (Fig. 5) illustrates graphically the change in the average quality of the milk produced by the cows in our University herd during the winter periods, 1898–'03 and 1903–'04. In order to make more apparent the relation between the amount of protein in the rations and the quality of milk produced, the percent of digestible protein in the total digestible matter has been platted in the upper part of the diagram and not the nutritive ratio, i. e. the reciprocal of the last figure in the nutritive ratio, 15.4 or 100/6.5 instead of 1:6.5, 14.3 or 100/7 instead of 1:7. etc. Charted this way it will be seen that the lines for digestible protein and percent of fat in the milk run in the same direction, either both upward or downward, in the case of all cows except three.

Connecticut (Storrs) Experiments. A study of the results of the feeding experiments with Connecticut dairy herds conducted by the Connecticut (Storrs) Experiment Station, 1892–1901, has been made with a view of adding further testimony as to the relation of food to quality of milk (81). These experiments have been conducted with farmers' herds which have been studied in two phases: *first,* under the system of feeding practiced by the farmers, and *second,* after the adoption of changes in this system suggested by the Station. The changes suggested resulted in the feeding of rations of narrower ratios and, as a rule, containing more digestible matter than those originally fed by the farmers. We shall not here take up space with descriptions of the separate experiments, but refer to the original reports and to the accompanying diagram (Fig. 6), showing the relation between the percent digestible protein in the total digestible matter of the rations fed and the percent of fat in the milk. These experiments show a similar relation to that already explained, a corresponding increase or decrease in the two factors in sixteen out of twenty-one cases.

Other Experiments. The results of experiments in the same line conducted at five different experiment stations have been charted in the same manner (see Fig. 7). These experiments are reviewed in detail in the tenth annual Connecticut report (82), and we shall not therefore here enter into further explanations concerning the plan of the experiments. We note here similar changes in the percent digestible protein in the rations and the percent of fat in the milk, in thirteen out of sixteen comparative trials, i. e., higher percent fat with narrower nutritive ratio and *vice versa,* as a general rule.

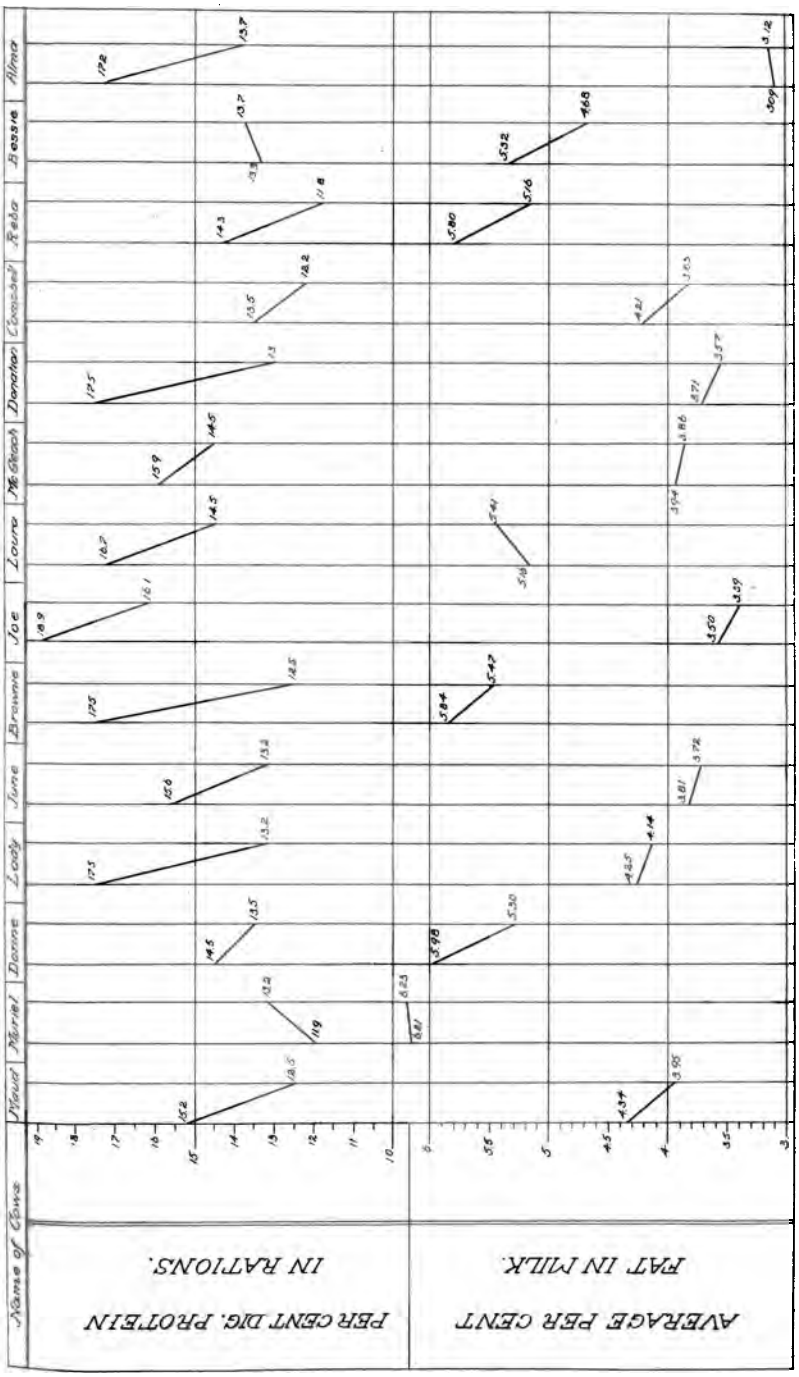

FIG. 5.—Relation between average percent fat in milk and percent digestible protein in rations fed to cows in the University herd, 1903–4 (first set of figures) and 1898–03 (second set of figures). With but three exceptions, the richer milk was produced on the more nitrogenous rations.

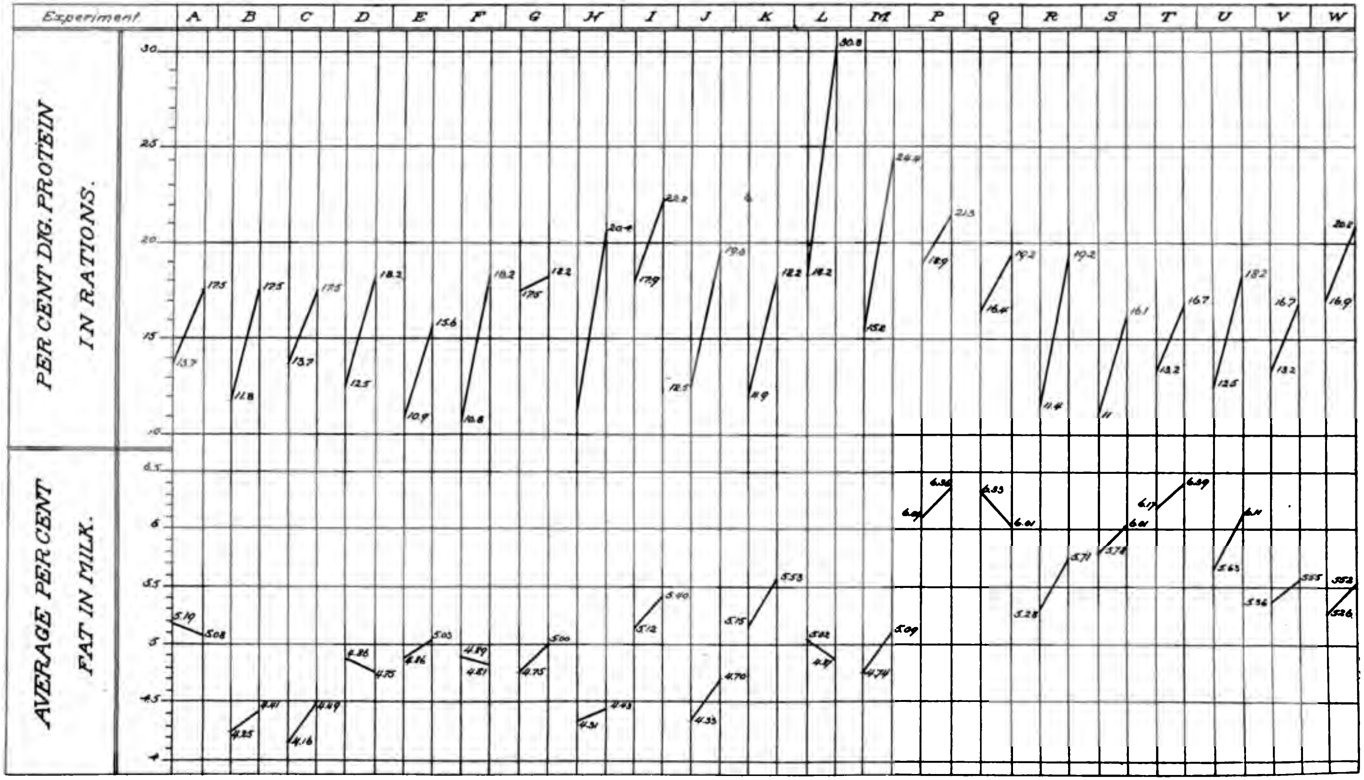

FIG. 6.—Relations between average percent fat in milk and percent digestible protein in rations fed to farmers' herds, under the direction of the Storrs (Conn.) Experiment Station. The first set of figures represent data for original rations, the second set those obtained when the rations had been changed so as to contain more digestible matter, making them at the same time of a narrower nutritive ratio. In sixteen out of twenty-one cases, the richer milk was produced on the more nitrogenous rations.

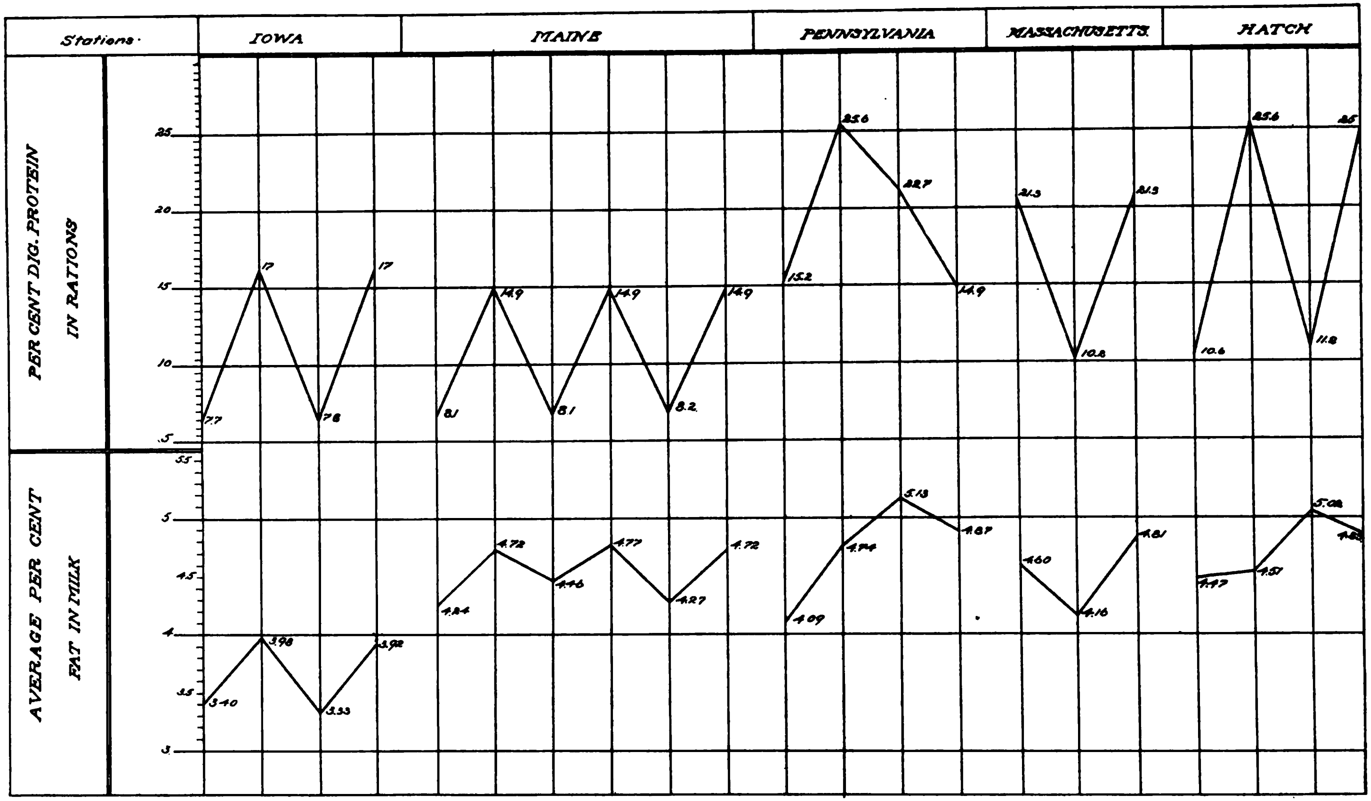

FIG. 7.—Relation of average percent of fat in milk and percent digestible protein in rations fed in experiments at Iowa, Maine, Pennsylvania, Massachusetts (State). and Hatch Experiment Stations. In thirteen out of sixteen comparative cases, the fat content of the milk increased or decreased with the percent of protein in the rations fed to the cows.

We have then experiments conducted at seven different stations, or under their immediate direction, which bear nearly unanimous testimony to the favorable influence of a high or medium protein feeding on the quality of the milk secretion. To this testimony may be added that furnished by an investigation conducted of late years by Cornell Experiment Station, an account of which has just come to hand (83). This investigation followed somewhat the same line as the Connecticut experiments referred to in the preceding; it was conducted for four years with a poorly fed and cared-for farmer's herd, which was kept with the Station herd during the two middle years of the investigation. While there the cows received the best of treatment and as much feed as they could consume to advantage. If we compare the average data for the second and third years with those for the first and fourth years for the seven cows that went through the whole period of four years, we have the figures shown below.

Average percent of butter fat in milk of seven cows.

Cow No.	Av. Per I & IV.	Av Per II & III.	Difference.
1	4.91 percent.	5.24 percent.	.33 percent.
2	4.26	4.67	.41
3	5.95	6.08	.13
4	3.55	3.76	.21
5	3.91	4.25	.34
6	5.01	5.11	.10
7	3.56	3.79	.23
Average			.25 per cent.

The results of these experiments are such as would be expected from what has been long known as regards the influence of high feeding on the milk secretion of previously underfed cows (see page 63). It is likely, however, that many farmers keep cows in a similar condition as these were before they were placed on the ample ration, at least during certain seasons or a part of the year. In such cases we may, therefore, confidently expect an improvement in the quality of the milk flow and an increase in the flow when better rations containing a larger proportion of protein and more total digestible matter are fed, and we may likewise expect, as a general rule, to obtain a somewhat better quality of milk when such rations take the place of rations of a wider nutritive ratio, even if the latter supplied sufficient amounts of food materials to amply nourish the cows and enable them to produce a good flow of milk, without causing any appreciable increase in their weights.

The testimony of recent investigations as to the relation of food to the quality of milk, presented in the preceding, is, in a measure, contrary to the commonly accepted views of writers on dairy topics. The evidence at hand does *not* show that there is no relation between the fat content of the milk and the character of the ration fed as to its nutritive ratio and the amounts of digestible protein contained therein. The question "Can the quality of the milk be changed by any definite system of feeding?" cannot, therefore, be answered in the negative, except so far as immediate and marked results are concerned. It can be said with absolute certainty that a cow which produces milk containing, say 4 percent of fat, on a ration that enables her to maintain her weight, cannot be fed in such a way as to increase the percent to 5, or even more, by any change in the system of feeding that we know of. But the evidence presented does show that, in the large majority of instances, a nitrogenous ration will produce milk containing a somewhat higher percent of fat than a ration of a wide nutritive ratio, and that differences of a few tenths of one percent in favor of the more nitrogenous rations may thus, as a general rule, be expected as the result of such a system of feeding.

ONE-SIDED CHANGES IN THE COMPOSITION OF MILK.

We may assume that changes in the composition of the milk might be effected in two directions through the influence of food: *first*, the solids of the milk might be increased and all their components to the same extent, i. e., the milk would become richer in casein, milk sugar and ash at the same time and to the same extent as it becomes richer in fat; *second*, there might be a one-sided change in one or more of the components of the solids, e. g., the fat or the casein. We have considered the former possibility in the foregoing pages so far as the percent of fat is concerned and need only supplement the information already given by stating that the changes to which we have called attention wherever full data have been obtained and published, apply to the other solids as well; the influence of the food on the milk secretion, when it has made itself noticed, has been in the direction of affecting the various solids of the milk to the same extent. So-called specific feeds which can change the relation of the milk solids to each other, rendering these proportionally richer in fat or casein, e. g., are not found. A number of feeds like palmnut meal, cocoanut cake, peanut cake meal, cotton seed meal, brewers' grains, malt sprouts, gluten feeds, molasses feed, "stock foods," have been believed by some authors, on basis of experiments made, to possess such an influence, but the evidence is conflicting, and the best information at hand does not support the claim; we are led therefore to look upon the results obtained in earlier work in this line as caused by errors of experimentation which seriously vitiate the value of so many of these experiments (see page 12; also ref. 76).

Our hope of improvement in dairy production must for the reason stated lie in a gradual increase in the proportion of milk solids in the milk through a correct system of feeding and through selection of milch cows producing milk of good quality, and not through a one-sided increase in the more valuable components of the solids, especially fat. It may be in order to call attention to two facts bearing on this subject which have become the accepted teachings of dairy authorities: *first*, that the bull is more than half the herd in so far as his influence on the quality of the milk produced by the offspring is concerned; and *second*, that efforts toward an improvement in the quality of the milk of cows are more likely to prove successful within a reasonable period of time, in the case of heavy milkers, than efforts toward the improvement in the flow of the milk of cows producing very rich milk; hence cows of the former kind are, in general, better subjects for experimentation and further development than those of the latter kind.

THE INFLUENCE OF FEEDING FAT OR OIL.

A new phase of the question of the possibility of changing the quality of the milk by special systems of feeding was brought forward by Soxhlet in 1896, when an account of a feeding experiment with two cows was published, in which the cows received fat in considerable quantities as emulsions of sesame oil, linseed oil or tallow in water (84). Although no details of these experiments were published, with exact information as to the method of conducting the feeding trials or the results obtained, beyond the final summary, the views of this author as to the effect of such feeding are well understood from the general discussion in his paper. According to his claim, fat in an emulsion is more easily digested than fed in any other manner, and if so fed, will decidedly increase the fat content of the milk; it is not claimed that the fat of the food or drink can be directly transmitted to the milk, but that it takes the place of body fat of the cows, which may then enter the milk and enrich this above its normal content of fat.

In view of the transformation of body fat into milk fat which we see occurring directly after parturition in case of cows that are quite fat when they freshen, this theory seems quite plausible, but further investigations along this line have proved it untenable, since the addition of oils or fat given either in the form of emulsion or otherwise has been found ineffective in bringing about the desired result beyond a brief period of time after this method of supplying the cow with fat is commenced. We need here only refer to the experiments with feeding oils and fat by Wood (85), Wing (86), Hills (87), Rhodin (88), Bartlett (89), Hagemann (90), Albert and Maercker (91), Winternitz

(92), Falke (93), Morgan *et al* (94), Beglarian (95), Lindsey (96), Malpeaux and Dorez (97), Harnoth (98), and Einecke (99)..

In some of these experiments the addition of oil to the ration apparently caused an increase in the percent of fat in the milk, but the same kinds of oil produced opposite effects in the case of different cows, and the only conclusion from all experimentation in regard to this question that we are justified in drawing is, therefore, the one given above.

EFFECT OF PASTURE ON THE COMPOSITION OF MILK.

It has been urged that the influence of pasture on the fat content of milk furnishes proof that the quality of the milk can be modified by the food which cows receive. A number of careful observations have been placed on record showing that the fat content of the milk produced by cows shortly after they are let out in the spring is, as a general rule, appreciably higher than during the weeks immediately preceding this time. It is only necessary to refer to the extensive summary on this point published by the Copenhagen Experiment Station (100), which gives the average fat content for ten consecutive years for three ten-day periods preceding and following turning out on pasture. These experiments were conducted on eight different farms, four to eight each year, and include data for 1961 fall-calving cows in all.

Effect of pasture on percent fat in milk.

YEAR.	WINTER FEEDING.			PASTURE.			No. of farms.
	Per. III	Per. II	Per. I	Per. I	Per. II	Per. III	
1890	3.26	3.31	3.37	3.63	3.41	3.33	
1891	3.29	3.32	3.38	3.55	3.32	3.28	4
1892	3.15	3.17	3.21	3.45	3.31	3.26	7
1893	3 17	3.20	3.23	3.43	3.30	3.28	8
1894	3.06	3.12	3.13	3.40	3.35	3.36	8
1895	3.16	3.20	3.18	3.41	3.30	3.26	5
1896	3.15	3.15	3.20	3.48	3.41	3.28	5
1897	3.13	3.15	3.16	3.43	3.32	3.30	5
1898	3.12	3.13	3.19	3.54	3.39	3.41	4
1899	3.07	3.05	3.11	3.42	3.32	3.23	5
Average	**3.15**	**3.18**	**3.21**	**3.47**	**3.34**	**3.30**	**1,961** Cows

The average yields of milk for the three periods on stable feeding was 21.2 lbs., 20.7 lbs. and 20.2 lbs, and for the three periods on pasture 21.7 lbs., 21.7 lbs., and 20.3 lbs. The highest yields of milk after the cows were let out came in some years during period I and in others during period II; the weather may have been the deciding factor in determining this result. After thirty days on pasture the fat content of the milk had decreased to about the percentage it would have reached if the cows had been fed in the stable and the percent of fat had continued to increase in the same ratio as during the last thirty days of stable feeding. The results of complete analyses of the milk which were made, suggest that the milk solids likewise increased when the cows were put on pasture, the percent of solids not fat for the six periods given being 8.72, 8.73 and 8.74 on stable feeding, and 8.90, 8.93, and 8.93 for periods I to III, respectively, on pasture. The non-fatty solids did not, therefore, decrease in the same way as the fat during the latter periods, but remained practically constant. This appeared to be due to a slight increase in the percentage of nitrogenous components of the milk during the last periods, since both milk sugar and ash remained nearly uniform before and after the cows were let out.

A similar percentage increase in the fat content of the milk of cows when they have been put on pasture in the spring was observed by Kjärsgaard with 19 different dairy herds of 4 to 99 cows each, averaging about 33 cows. The average fat content obtained on winter feed was 3.33 per cent, with ranges in case of individual herds 3.09 to 3.56 percent. On pasture, *first* test (20 days later) 3.67 percent, ranges 3.23 to 4.04 percent, *second* test (40 days later) 3.60 percent, ranges 3.34 to 3.97 percent (101).

In this country Hills studied the effect of the change from barn to pasture on the fat content of milk for five years (102), and concludes that "the evidence appears overwhelming that cows on early pasturage, May and June, make not only more but richer milk than during the last months of their barn life." In the Vermont report for 1902 (103) the same author discusses the results of eight years' work in this line and somewhat modifies this conclusion.

Dean (104) publishes corroborative evidence on this point. The average fat content of the milk of the dairy herd at the Guelph Agricultural College for 17 days before the cows were turned out to pasture was, in the morning, 3.69 percent; in the evening, 3.08 percent; and for the first 17 days on pasture, in the morning 4.36 percent; evening, 4.47 percent.

The evidence presented shows that we may consider the improvement in the quality of the milk on pasture during the first weeks an established fact. Although this is in accordance with the results of recent experiments on the relation of food to quality of milk, it is a question whether we would be justified in ascribing this improvement to the change in the food of the cows, since the food is only one of the factors which has been changed; the general feeling of well-being of the cows after their long confinement in the stable, the outdoor life in the pleasant spring weather, the influence of sunlight, the aromatic and succulent pasture grass as contrasted with the more or less coarse, unpalatable roughage fed during the last stages of the winter feeding, doubtless all combine to stimulate the vital processes concerned in the milk secretion and to bring about an improvement both in the quantity and the quality of the milk produced.

Feeding Grain to Cows on Pasture. A question of great practical importance to dairymen which may be briefly considered here, is that of the economy of feeding grain to cows on pasture; investigations at the experiment stations at Cornell (N. Y.), in New Jersey, Kentucky, Kansas, North Dakota, Mississippi and Utah (105) furnish decided evidence that the practice is not an economical one, in so far as immediate returns are concerned, when pasturage is abundant and of good quality. "Feeding grain on pasture is, in general, unprofitable; profitable only when pastures are short"; "We did not receive enough additional milk to pay for the grain"; "We were evidently not paid for meal on good pasture," are some of the conclusions drawn. These conclusions refer, however, to the *immediate* returns; when the practice of feeding grain is continued for several seasons, the evidence at hand indicates that an increased production, especially in the case of younger animals, will be obtained which will be sufficient to more than pay for the grain fed.

INFLUENCE OF FOOD ON THE FLAVOR AND QUALITY OF MILK AND BUTTER FAT.

We have seen that there is considerable conflict in the testimony as to the influence of the food on the fat content of the milk and its chemical composition in general. Such is not the case, however, in regard to the influence of the food on the flavor and some of the physical properties of the milk and butter fat produced by the cows or on the chemical composition of the butter fat. It has been known almost as long as man has kept cows for the production of milk and other dairy products, that good pasture grass produces milk, butter and cheese of excellent flavor; butter produced on early summer pasture is of standard color in nearly all dairy countries. The beneficial influence of pasture grass on the milk and butter is generally ascribed to the presence of fine aromatic principles in young grass which may also be preserved in the hay by careful methods of curing, and in either case, will influence favorably the aroma or flavor of the products of the cow. In the same way the presence of certain weeds in the pasture, like wild garlic, is known to affect deleteriously the flavor of both milk and butter, and many feeding stuffs, like cabbage, turnips, silage, rye, etc., will produce an "off flavor" in either milk, butter or cheese if fed directly before or during milking (106).

In the case of the effect of feeds on the flavor of the milk, only general information is at hand, as there is no chemical or other test that will show by absolute figures the lowering of the quality of the product in the case of milk, but the matter stands differently in the case of butter since the oil or fat in a feed stuff will to a large extent determine the quality and chemical properties of the fat of the milk, which again affects the mechanical properties (the "body") as well as the appearance and flavor of the butter made from the milk. Cotton-seed meal is a typical example of the influence of a feeding stuff in this respect. As first called attention to by Harrington (107) and Wiley (108) the influence of the cotton-seed meal on the quality of the butter produced is seen in a high melting point and low volatile-acid number of the fat and a white appearance and poor flavor of the butter. The Becchi reaction for cotton-seed oil is also obtained in butter produced by cows that have been fed considerable quantities of cotton-seed meal. The effect of corn oil and corn refuse feeds high in oil (fat) has been found to go in the opposite direction to that of cotton-seed meal, since foods of this class produce a soft butter; where only a small amount of fat is present in these feeds, the butter produced will be hard. (See below.)

The influence of a large number of feeding stuffs on the quality of the butter has been studied by many experimenters during the past twelve or fifteen years, and our knowledge of the effect of different feeds in this respect is now quite complete. A mere reference to the main feeds experimented with must suffice here. The most important class of feeding stuffs which has received attention is that of the refuse feeds from oil mills; in this connection the feeding of the oil or oil-bearing seeds and of pure fats of various kinds may also be referred to.

I. Oil-Mill Refuse Feeds.

Cocoanut Cake, Ruffin (109), Heinrich (110).
Cotton Seed Meal, Curtis & Harrington (111), Lindsey (112), Lupton (113), Thorpe (114), Ruffin (109), Moore (115), Morse and Wood (116), Speir (117), Hunt (118), Stein (119).
Linseed Meal, Lindsey (112), Weigmann (120).
Peanut Cake, Ruffin (109), Heinrich (110).
Poppy Seed Cake, Weigmann (120).
Rape Seed Cake, Wood (116), Heinrich (110).
Sesame Cake, Stein (119), Thorpe (114), Pfeiffer (121).
Sunflower Seed Meal, Wood (116), Heinrich (110).
Whale Flesh Meal, Sebelien (122).

II. Oils and Fats.

Almond Oil, Beaumert & Falke (123).
Cocoanut Oil, Beaumert & Falke (123).
Corn Oil, Lindsey (124), Hills (125).
Linseed Oil, Lindsey (112), Hills (125).
Palm Oil, Klien (126), Morse (116), Lemmermann & Moszeik (127), Hills (128).

Peanut Oil, Lemmermann & Moszeik (127).
Rape Seed Oil, Klien (126).
Sesame Oil, Klien (126), Baumert & Falke (123).
Beef Tallow, Lemmermann & Moszeik (127).
Olein, Morse (116).
Stearin, Morse (116).

III. Cereals and Refuse Feeds.

Buckwheat Middlings, Hills (128).
Corn, Morse & Wood (116), Lindsey (124), Friis (100).
Oats, Hills (129).
Rye, Weigmann (120).
Dried Brewers' Grains, Hills (129).
Germ Oil Meal, Hills (128-9).
Gluten Meal or Feed, Lindsey (112, 124), Wood, Parsons and Morse (116), Hills (125, 129), Smith (130), Bartlett (131).
Malt Sprouts, Hills (129).
Peat Molasses, Lassen (132).
Wheat Bran, Hills (125), Weigmann (120).

IV. Coarse Feeds.

Apple Pomace, Hills (129).
Corn Silage, Hills (125, 129).
Grass, Mayer (133), Morse (116).
Grass, Siloed, Mayer (133).
Pea Straw, Mayer (133).
Potatoes, Hills (125, 129), Wilson *et al* (134), Smith (130).
Roots, Smith (130), Lassen (132).
Sugar Beets, Wilson et al (134).
Sugar Beet Pulp, Friis (100), Watson (135).
Sugar Beet Tops, Roussel (136).*

INFLUENCE OF INSUFFICIENT RATIONS ON QUALITY OF MILK PRODUCED.

We have already mentioned that in the case of rations which do not furnish sufficient nutriment to maintain the normal weight of the cows, the quality of the milk produced is likely to suffer; this fact was illustrated by the results of a digestion experiment with corn silage and corn fodder as exclusive feeds for two milch cows, which was conducted by the writer in 1888 (137). The animals on this experiment received less than maintenance requirements of digestible protein and scarcely more dry matter than called for by the maintenance ration of Wolff and other authorities; hence both cows lost in weight. The following table gives the main results bearing on this point which were obtained on the experiment.

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*See also summary on the subject by *Frear*, Agricultural Science, 7, p. 120; *Fleischmann*, Milchwirthsch, 3rd ed., p. 74-75; *Kirchner*, Handbuch d. Milchwirtschaft, 3rd ed., p. 344-6, &c.

Relation of rations fed, body weight of cows, and milk production.

Date.	Feed.	Cow No. I.			Cow No. II.		
		Milk.	Fat.	Body weight	Milk.	Fat.	Body weight
		Lbs.	Per ct.	Lbs.	Lbs.	Per ct.	Lbs.
Feb. 14 to Feb. 20	Fodder corn..	15.2	4.50	855	21.6	3.22	992
Feb. 21 to Feb. 26	Fodder corn..	13.4	4.72	823	18.5	3.13	976
Feb. 27 to Mar. 6......	Corn silage ..	12.81	4.26	841	18.3	3.16	1,011
Mar. 7 to Mar. 13	Corn silage...	12.77	4.35	809	18.1	3.04	986
Mar. 14 to Mar. 20......	Fodder corn..	12.6	4.76	778	17.2	3.19	926
Mar. 21 to Mar. 27......	Fodder corn..	....	....	....	16.1	3.16	917

Cow No. 1 received 10 lbs. bran daily in addition to the fodder corn from March 15th on and the experiment with this cow was discontinued on March 18th. The quality of the milk produced by cow No. 2 was not materially affected by the scant feeding, in spite of the decrease in the body weight of the cow during the experiment. But a marked change took place in the quality of the milk of cow No. 1 during the fodder corn and silage feeding, and when she received a sufficient supply of food through the addition of bran to the fodder corn there was an immediate improvement in the quality of her milk.

Arenander's analyses of about 2,000 samples of milk delivered at creameries in northern Sweden (138) show that during the latter part of the winter when cows in this region on many farms eke out a meager living on marsh hay or old stack hay, the fat content may be reduced by one or two percent below normal in case of individual cows. The following results will be of interest in this connection.

Fat contents of milk as affected by quantity of food.

Period.	VARIATIONS IN PER CENT OF FAT IN MILK.		
	Maximum.	Minimum.	Average.
I. June-Sept., pasturage.........	5.0-5.8	2.65-2.9	3.71-4.25
II. Oct.-Dec., ample stable feeding	4.1-4.2	2.30-2.9	3.32-3.52
III. Jan -May, scant stable feeding	4.0-4.6	1.10-1.9	3.20-3.30

THE NUTRITIVE RATIO OF RATIONS FOR DAIRY COWS.

In a number of experiments quoted in the preceding we have already referred to the nutritive ratio of the various rations experimented with and incidentally seen that a narrow nutritive ratio is likely to improve the quality of the milk secretion, although the tendency in this direction, as shown by many of the experiments on this point that have been published, is often too small to be of much practical importance. We shall now consider the importance of the nutritive ratio to the milk producer, i. e., the economical aspects of narrow and wide ratios. The effect of the feeding of a certain ration on the milk secretion will show itself in one or both of two directions, an improvement in quality or increase in yield. Evidence as to the effect of a certain ratio in the former direction may be gleaned from a number of experiments already quoted, and further evidence on this point will be presented in connection with the results as to the influence on the milk yield and the economy of the production given in the following.

In comparing the influence of certain feeding stuffs on milk production or of certain combinations of feeds with each other, it is necessary that the total amounts of nutrients supplied in both cases be at least approximately the same; that is, a certain amount of digestible carbohydrates and fat must be replaced by the same amount of digestible protein; only when this is the case, when there is a change in the quality of the ration only and not in its quantity, can differences in the effect of different nutritive ratios be studied with any certainty. In many of the experiments made on this subject this fundamental requirement has not, however, been met, and an element of uncertainty has thereby been introduced which considerably reduces the value of the experiments and of the deductions that have been or may be drawn from the results. (See p. 12.)

Attention has already been called to the fact that the nutritive ratio of the Wolff feeding standard for dairy cows is 1:5.4, and that up to the beginning of the nineties this ratio was quite generally considered a safe one toward which to aim. The American practical feeding ration based on more than 100 rations for dairy cows, as actually fed by leading American dairymen, provided for a ratio of 1:6.9; in the Wolff-Lehmann standards published in 1897 the ratios varied according to the amount of milk produced by the cows, from 1:4.5 for cows yielding 27.5 lbs. of milk daily, to 1:6.7 for cows with a daily milk yield of 11 lbs.

The Connecticut Station in 1893 suggested tentatively a ratio of 1:5.6 with 2.5 lbs. digestible protein. The studies conducted by that Station for a large number of years past (82) have shown very clearly, as has also been found in numerous direct experiments, that in so far as physiological effects are concerned, narrower ratios (i. e., 1:5.5 or less) will, as a rule, give larger yields of both milk and butter fat than will be obtained with wide ratios. A few typical experiments in which this subject has been studied, may here be mentioned.

Wisconsin Experiments. The experiments conducted by the writer during 1893 and 1894 on the value of oil meal, corn meal and bran (139), furnish a good example of the effect of different nutritive ratios, from the fact that nearly the same quantities of nutrients were fed in case of all rations, and because of the precautions taken in the conduct of the experiments as to number of animals included, length of feeding periods, etc. When the yields of milk and of fat are summarized we find that there was an increase on *oil meal* over *corn meal* of 6.0 percent of milk and .9 percent of fat; there was an increased yield on *bran* over *corn meal* of .9 percent milk and 3.3 percent fat, and on *oil meal* over *bran* of 5.7 percent and 2.4 percent of milk and fat, respectively. The difference between these figures is not sufficiently large to be of much importance, and we may say, in general, that there was practically no difference in the immediate effect of the wheat bran and corn meal rations (nutr. ratio, 1:8.1 and 1:9.5, respectively) on the yield of milk, and that there was a small difference in favor of the oil meal ration (nutr. r., 1:6.0) over either feed. As regards the production of butter fat, both oil meal and bran gave slightly better results than corn meal. Considering, however, the cost of the three feed stuffs, the wheat bran becomes the most economical food under the conditions generally existing throughout the Northwest and in large sections of our country where dairying is an important industry.

The results strongly suggest that, given a good, fairly nitrogenous basal ration, an addition of bran or corn meal rather than oil meal is in the line of economy. This result corroborates earlier work at this Station by Armsby (140). This author showed in 1886 that in his own as well as in most experiments on this point published at that time, the narrower nutritive ratio was the more favorable to milk production, but since nitrogenous feed stuffs on the market are generally more expensive than the carbonaceous ones, it is not advantageous, on account of the financial aspects of the case, to use protein foods for the sake of increasing the proportion of protein in the food of milch cows.

New York (Cornell) Experiments. Experiments were conducted by Anderson for 22 weeks during each of two winters in a study of the influence of narrow, medium and wide ratios on milk production (141). The rations fed during the first year 1895-96 to nine cows, three in each lot, supplied about 16 lbs. total digestible matter and had a nutritive ratio of 1:4.5, 1:6.0 and 1:9.0 for the narrow, medium and wide rations, respectively. The nutritive ratios of the corresponding rations fed during the second year were 1:4.3, 1:5.7 and 1:9.3, with the same amount of digestible nutrients in the rations as before in all three cases. The average data for the two years as regards the quality of the milk of the cows and the decrease in the amounts of milk and in fat production during the experiments are shown in the following table, also the number of pounds of dry matter required in each ration to produce a hundred pounds of milk and one pound of butter fat.

Average data on experiments with narrow, medium and wide ratios.

	Year.	Narrow (1:4.3-4.5).	Medium (1:5.7-6.0):	Wide (1:9.0-9.3).	AVERAGE FOR BOTH YEARS.		
					Narrow.	Medium	Wide
Per cent. fat in milk...... (arithmetrical mean)	1895-6	3.48	3.42	3.44	3.38	3.48	3.68
	1896-7	3.28	3.55	3.98			
Decrease in yield of milk, per cent..................	1895-6	17.5	18.0	15.5	17.7	10.5	15.0
	1896-7	17.8	3.0	14.4			
Decrease in yield of fat, per cent.............	1895-6	12.0	12.0	12.0	13.8	9.0	11.2
	1896-7	15.6	6.0	10.3			
Digestible protein in av. ration, lbs................	1895-6	2.90	2.25	1.60	2.99	2.31	1.58
	1896-7	3.08	2.37	1.56			
Digestible carbh. and fat in av. rations, lbs	1895-6	13.23	13.65	14.37	13.20	13.64	14.42
	1896-7	13.17	13.63	14.47			
Dry matter eaten per							
100 lbs. milk	1895-6	90.2	102.8	98.3	97.5	93.0	95.7
	1896-7	106.6	85.2	92.8			
1 lb. fat......	1895-6	26.0	30.1	28.7	28.8	26.6	25.9
	1896-7	32.3	23.9	23.4			

Taking both experiments into account, it would seem that the medium ratio, 1:5.7 to 1:6.0, had on the whole a more favorable influence upon the continued production of milk and butter fat than either the wide or the narrow ratios, and this ratio was also the more economical one as regards the amounts of dry matter required for the production of a unit of milk and butter fat. However, the results go in different directions during the two years, and no more definite general conclusion can be drawn from them than that the narrow nutritive ratio did not always give the larger, nor the more economical production.

Pennsylvania Experiments. The deductions of Hayward from the data obtained on three feeding experiments with milch cows conducted at the Pennsylvania Station during the years 1896–99 (47) are valuable in this connection since the author in these experiments made a special study of the influence of the nutritive ratio upon the economy of milk and butter production. Hayward concludes: "The nutritive ratio between the limits of 1:3.4 and 1:11.3 had no effect upon the quantity or quality of milk production.

1.3 pounds of computed digestible protein was sufficient for a 1,000-pound cow in full milk, the other conditións necessary to her welfare being met (142).

Within certain limits, the quantity, digestibility, and palatability of the food, and its effect upon the animal's general system was of more importance than the relative amount of digestible protein and carbohydrates the ration contained.

The individuality of the cows experimented upon is an important factor to be reckoned with in investigations of this kind." (See p. 12.)

New York (Geneva) Experiments. Wheeler discusses the relation of nutritive ratios to milk production in a comprehensive study of the immediate effect on milk production of changes in the ration, based upon nearly 1,000 records of feeding trials with milch cows at the Geneva (New York) Experiment Station (143). He finds that moderate changes in the nutritive ratio within the ordinary limits had considerably less effect on the milk flow than did the changes in the amount of total digestible organic matter, but that, in general, a narrowing of the ratio had a favorable effect on milk production, while a widening of the ratio tended toward the reverse. When the nutritive ratio was narrowed, but kept wider than 1:6.0, no change occurred in the average amount of digestible dry matter consumed for each pound of milk solids produced. When rations with a narrower ratio than 1:6.0 were made still narrower, there was the same increase in the amount of digestible dry matter required for each pound of milk solids as when the corresponding ratios were made wider but kept narrower than 1:6.0.

Minnesota Experiments. This is in line with the conclusions to which Haecker was led in his investigations on the protein requirements of dairy cows (144). In these experiments he found that the product yielded on the different rations fed, which had nutritive ratios ranging between 1:6.3 and 1:9.7, bears a closer relation in quantity to total nutrients consumed than to the protein supply or to the nutritive ratio of the rations. Rations having a nutritive ratio of 1:7.7 or 1:9.7, respectively, were found to be as effective in the production of milk, butter fat and milk solids as was the one having a nutritive ratio of 1:6.3.*

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*See also Lawes and Gilbert, "The Feeding of Animals," *loc. cit,* page 115; Steinbrück, "Die Rentabilität d. Milchviehhaltung," Kühn, Berichte, 15, p. 157.

Copenhagen Experiments. In the cooperative cow-feeding experiments conducted by the Copenhagen Experiment Station to which reference has already been made (see page 49), the nutritive ratios of the rations fed have varied considerably, viz., from 1:9.5 down to 1:3.5. The rations experimented with were, generally speaking, similar to those commonly used on Danish dairy farms. They were modified in some cases in order to test the value of special systems of feeding, but the changes made were always such as might be adopted as the constant and normal feeding practice on these farms. The experiments conducted up to 1901 have been summarized by the Station so as to show the relation between the nutritive ratios of the rations fed and the amount of milk produced; we have seen that no appreciable differences were found in these experiments with respect to the quality of the milk produced, and the influence of different rations on the milk yield is, therefore, the only point to be considered, in addition to the economy of the various rations experimented with, concerning which the published reports do not furnish any information and which would apply to Danish conditions only. The following table has been obtained from a chart published in the 53rd report of the Copenhagen Station (145). The number of food units (replacement values, *foderenheder)* required for the production of 100 lbs. of milk expressed in relative figures, the yield obtained with a nutritive ratio 1:6.0 being placed at 100, will be found for different nutritive ratios from 1:9.5 to 1:3.5; in the same way the corresponding nutritive values of the different rations *(näringsenheder)*, i. e., the amounts of digestible protein, carbohydrates and fat in the various rations reduced to a single figure by a method of calculation not explained in detail in the report, were also referred to a relative milk production. The resulting data were as follows.

Relation of nutritive ratios to milk production.

Nutr. ratio.	Milk per food units.	Milk per nutr. values.	Nutr. ratio.	Milk per food units.	Milk per nutr. values.	Nutr. ratio.	Milk per food units.	Milk per nutr. values.
1:9.5.....	98.3	92.9	1:7.0	99.4	97.5	1:4.5	97.0	100.3
9.0.....	98.4	94.2	6.5	99.9	98.8	4.0	96.4	102.8
8.5.....	99.2	96.8	6.0	100.	100.	3.5	98.7	104.2
8.0.....	98.2	95.9	5.5	99.4	100.2	....	....	....
7.5.....	99.3	97.4	5.0	99.2	101.3	....	....	....

These results are represented graphically on chart No. 8, on which the various nutritive ratios, 1:9.5–3.5, are placed as abscissas and the relative milk yields, 92–104, are given as ordinates. We note that the difference in the effect on the milk yield, between the nutritive ratios 1:8–9 on one hand and 1:4–5 on the other, is very slight, since the curve for food units does not vary greatly from the horizontal, i. e., the efficiency of the rations with nutritive ratios within these limits are practically equal when the different feeding stuffs were given in the proportions expressed by their replacement values (see page 5). The curve for nutritive values, on the other hand, rises gradually from the widest to the narrowest nutritive ratios. The cause is to be sought in the relative efficiency of the different kinds of nutrients in feed rations when a ration is changed so that the sum total of nutrients remains the same but the relations between the nutrients, i. e., the nutritive ratios, vary. Every time a pound of protein is replaced by one pound of carbohydrates, the result is shown on the curve to be a decrease in the yield of milk. The superior value of protein foods in stimulating the milk-secreting power of cows is plainly shown from the preceding summary and from the chart; the economy of heavy nitrogenous feeding is then again brought back to the question of the relative prices of cattle foods.

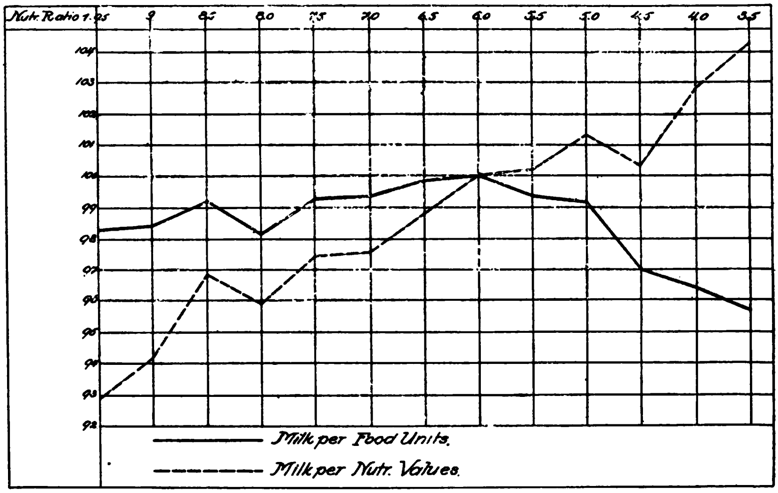

FIG. 8.—Relation of nutritive ratios to milk production. Between nutritive ratios of 1:8.5 and 1:5.0 no appreciable difference was found in the amount of milk produced per unit of food eaten; with more nitrogenous rations a relatively larger production of milk was obtained.

Revision of Prices Changes Economy of Feeding. The difference between the teachings of physiological effects and economic considerations is brought cut in a striking manner by Henry (146). The rations fed by nine Connecticut farmers to their dairy herds were changed so as to contain more protein, on the recommendation of the Storrs Experiment Station in their studies of rations for dairy cows (82). The amount of protein was increased, on the average, from 1.68 to 2.17

pounds, and the nutritive ratio narrowed from 1:7.5 to 1:5.6. According to Connecticut prices for feeding stuffs this change brought about an average saving in feed cost of about 6 cents per hundred pounds of milk produced and 2 cents per pound of butter. If, however, the calculation of the economy of these rations be based on western instead of Connecticut prices of feeding stuffs, Henry shows that the account would be against the narrow rations and that the cost of feed required for the production of a hundred pounds of milk and one pound of butter would be increased by 6 cents and .8 cent, respectively, by introducing the changes in the rations recommended, by which their ratios were brought down to near the Wolff or the Wolff–Lehmann standards.

Average Prices of Feeding Stuffs. As previously suggested, prices of different feeding stuffs vary to a considerable extent in different parts of our country. As an illustration we give market prices of five of our common feeding stuffs in different states of the Union, from data given in the last feeding stuff bulletins published by the Experiment Stations in the respective states (147).

Average prices of concentrated feeds per ton, 1903.

	New York.	Connecticut.	Wisconsin.
Wheat bran	$19 33	$22 75	$17 00
Wheat middlings	23 10	25 50	19 80
Corn and oats, ground	27 80	....	22 35
Oil meal	31 80	30 77	28 00
Cotton seed meal	28 80	29 04	30 00

We notice that the highly nitrogenous feeds, oil meal and cotton seed meal, were sold at about the same prices in the different states given in the table, while the more carbonaceous feeds, bran, middlings, corn and oats, cost up to one-third more in the east than they did in this state. In earlier years the differences in prices were considerably larger than those shown above, owing to the increase in the cost of carbonaceous feeding stuffs in the west during the last few years. It follows, therefore, that no general rules can be given which will apply to our whole country as to the economy of different systems of feeding farm animals. Generally speaking, narrower nutritive ratios can be fed to advantage in the east than in our section of the country; it is evident that the most economical rations that our farmers can use in feeding dairy cows must be made up largely of common farm grains or mill feeds, with only small quantities of oil meal, gluten meal or feed, cotton seed meal, distillers' or brewers' grains, etc., these being fed both for the purpose of supplying a variety to the rations and rendering them more palatable, as well as on account of the fact that the addition of these feeds will render the rations more effective for the production of milk and butter fat.

The nutritive ratios of the rations fed to cows in our University dairy herd during the past winter ranged between 1:5.3 and 8.4, average 1:6.1. It will be remembered that the production of butter fat and the net profit returned by the cows on this system of feeding was larger than during the preceding years when wider nutritive ratios (average 1:7.2) were fed. According to the teachings of recent work in this line a nutritive ratio of between 1:6 or 7 is to be recommended for farmers in the central northern states. Considerable latitude should, however, be allowed in regard to nutritive ratio to be fed, according to the production and the individual characteristics of the cows, whether or not they show a tendency to fatten easily when in milk.

With the evidence before us which has been accumulated during the last decade or two, it must be admitted that the importance of providing a definite nutritive ratio in feeding dairy cows has been greatly overestimated by writers and lecturers on the subject of animal nutrition. While recent work shows that we would not be justified in applying the results of Kellner's extensive investigations with fattening sheep and steers to dairy cows as well, on account of the apparently larger need of the latter class of animals of protein substances, they apply more nearly to them, considering the economical aspects of feeding cows, than was generally believed a dozen years ago or more. Kellner's conclusions as regard rations for fattening sheep and steers were as follows: "Special stress need not be laid on the supply of protein in the rations; the nutritive ratio may range between 1:4 and 1:10; the increase in live weight (and production) remains the same when similar quantities of digestible nutrients are fed, provided that protein and non-nitrogenous nutrients be supplied in as easily digestible form as possible with the same allowance of roughage, which should not exceed the minimum requirement of animals" (148).

RATIONS FOR DAIRY COWS.

The general subject of feeding standards for farm animals and especially for dairy cows was considered in the introduction to this bulletin, and the various standard rations suggested by investigators in Europe and in this country were referred to and briefly discussed. It is of interest at this point to examine into the bearing which the information given in the preceding as to the relation of food to milk production will have on our attitude toward these standards.

The feeding standards of Wolff, Wolff-Lehmann, Maercker, Kühn, etc., are meant to express the amounts of digestible food materials which will produce maximum results in the case of farm animals kept for various purposes. The economy of the systems of feeding conducted in accordance with the standards does not enter into consideration. They are expressions of the physiological effects of foods upon the production of body weight or animal products in the case of different kinds of farm stock. The prices of feeding stuffs on the German feed market may, in a general way, have been considered by Wolff in formulating his feeding standards, but prices of feeds and products differ greatly in different countries and, in the same countries, during a series of years, so that if, for instance, the cost of nitrogenous feeding stuffs were such nearly a half century ago, when the Wolff feeding standards were first published, that considerable amounts of protein could be fed economically, this is not necessarily the case in Germany at the present time. The only feeding standard, if any, which can be of general and permanent value is one which shows the combination of different food components that will produce the optimum physiological effect under given conditions of feeding, for instance, in feeding for milk or for growth; which does not, therefore, take into consideration the expense of reaching this result. The formulating of such standards has great scientific value and is indirectly of considerable practical importance, as they place before the feeder an ideal which he may approach as nearly as the special conditions by which he is surrounded will allow, but which cannot in individual cases receive first consideration.

Another method of obtaining information as to the food requirements of different farm animals is to observe the feeding practices of progressive business farmers who have made a study of their profession and have adopted definite systems of feeding as a result of their personal experience of the effects of foods and their relative economy. Farmers of this class are perhaps not very numerous, but they are found here and there in most states, and it was on the basis of such testimony that the data obtained by the writer in the investigation of the feeding of dairy cows mentioned in the preceding were collected, and that the so-called American practical feeding ration was formulated. There is not necessarily any conflict between the teachings of the feeding standard and the practical feeding rations published by the writer or by dairy scientists who have adopted a similar course of investigation (149). Indeed, the two rations may be entirely dissimilar and still both be correct, but in the latter case the practical feeding ration would be the only safe guide for the farmer, since it alone considers the economics of the farming operations, the relation between the cost of feeds of different character and of the products obtained.*

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*For a pithy discussion of physiological, practical and average feeding standards, see Vermont Experiment Station, Bull. No. 81, pp. 15–16.

The investigations which have been briefly reviewed in the preceding, and many others that might be quoted, the teachings of which go in the same direction, render pertinent, however, the question of the value of feeding standards or standard rations in specific cases. We have seen that the amount of protein and other food components which cows require for the production of units of milk and milk solids vary greatly with different animals as well as with the same animals in different lactation periods and under varying conditions in other ways; also that rations supplying varying amounts of digestible nutrients will differ widely in their influence on milk production. The general trend of the results of feeding experiments with milch cows is in the direction of showing that protein feeds possess a somewhat higher value for milk production than feeding stuffs of a more carbonaceous character, but the profitable extent of feeding such feeds must be determined largely by local conditions. With a fair amount of protein in the ration supplied of farm-grown foods, the narrowing of the ration fed, by an addition of protein foods, is not a matter of prime importance. The testimony furnished by studies of the feeding practices conducted under a variety of conditions plainly shows that excellent results may be obtained by the use of quite wide ratios; a liberal supply of digestible matter in the rations of cows that are good producers is of importance, irrespective of the proportion of nitrogenous nutrients found therein, if the rations contain a minimum of protein, which may be placed for different cows at from 1.3 to 1.5 lbs. (150). At the same time it should be borne in mind that the cows are most likely to produce milk of the best quality of which they are capable, on rations that contain a fair amount of protein, and have nutritive ratios not wider than about 1:7, for cows in full flow of milk; under ordinary conditions in the north central states a somewhat narrower nutritive ratio than this will, generally speaking, prove profitable, where the permanent effect on the production of the herd is kept in view.

An immense amount of dogmatic preaching has been indulged in, both in this country and abroad, in regard to feeding standards and questions of rations for farm animals, in general, during the last few decades, and it is not surprising to find the most definite rules and formulas laid down by popular writers on dairy subjects. The array of evidence that has been brought forward of late years has, however, made the work of the mathematical feeder less popular, and students of animal husbandry and observing farmers are coming to look more and more with suspicion on any system that aims to reduce the feeding of farm animals to a definite schedule. There is no royal road to success, and none to successful feeding of dairy cows. The differences in the peculiar organization of different cows preclude the formation of general rules of feeding practices, and we are left largely to consult each individual cow as to how a large and economical production may be secured. An increase in live weight in the dairy cow is antagonistic to milk production, and our main aim should be to feed such foods and combinations of foods as will stimulate a large secretion of milk without at the same time causing a material increase in body weight above normal. This is not a new system of feeding, but one that was advocated by dairy authorities fifty years ago or more (151). The keynote to success in feeding dairy cows lies in this system, and in individual feeding, by which the wants of each cow are studied and catered to, each cow being fed such quantities of feed as she can use economically in the production of milk. The intensity of the feeding will, as previously stated, necessarily depend upon local conditions, the relative cost of roughage and concentrates, the prices obtained for products, the production of the cows in the herd and their capacity for further development along dairy lines, etc., conditions which are not alike on any two farms and which make it necessary for the dairy farmer to understand the principles underlying the feeding of dairy cows, rather than to have special rations figured out for him by persons who are unfamiliar with his cows and know next to nothing of the particular conditions under which his dairy is conducted.

CONCLUSIONS.

The discussions presented in the preceding pages may be briefly summarized as follows:

1. Economic production of milk and butter fat by dairy cows as regards food consumption is dependent on a number of factors, chief among which is the capacity of the cow for converting considerable amounts of food materials into milk without at the same time gaining in body weight.

2. Other factors are, the stage of the lactation period, the age of the cow, the amount of feed eaten, and the character of the rations fed as to succulence and nutritive ratio.

3. The amount of nutrients consumed over and above maintenance requirements per 100 pounds of milk ranges in the case of different cows, at least, between 26.8 and 80.2 pounds of dry matter, and per one pound of butter fat between 6.8 and 18.6 pounds of dry matter. The amount of net digestible protein consumed has in the same way been found to range from 3.16 to 9.07 lbs. per 100 pounds of milk produced, and from .76 to 1.70 pounds per pound of butter fat.

4. Good dairy cows have the power of producing a unit of milk or butter fat from a smaller amount of dry matter than cows of less pronounced dairy capacity.

5. The production of a unit of rich milk calls for a larger supply of valuable food components than is required in the case of poor milk. For every percent of increase in the fat content of the milk, the amount of net dry matter required for the production of 100 pounds increases about 8 pounds, and the amount of net digestible protein increases about .8 lb. The amount of nutrients consumed per unit of butter fat produced decreases slightly with an increasing fat content of the milk, viz., about .6 lb. of net dry matter and .08 lb. protein for each percent of fat in the milk.

6. The amount of food materials required for the production of a unit of milk or butter fat is nearly three times as large toward the close of the lactation period as at its beginning.

7. Heifers require a larger proportion of nutrients for the production of a unit of milk or butter fat than do older cows. Optimum results as regards the efficiency of the food consumed are obtained when the cows have reached about seven years of age; the period of usefulness of cows depends on their constitutional strength and the system of feeding and handling to which they have been subjected.

8. Recent evidence goes to show that the food of the dairy cow influences the quality of the milk produced to this extent that the cow will yield a maximum flow of milk of the highest fat content which she is capable of producing, on rations relatively rich in nitrogenous substances. The productive capacity of the cow, the prices of feeding stuffs and of the milk products, are the main factors, that will determine how highly nitrogenous rations can be fed to advantage. Under ordinary conditions in the north central states it will not, as a rule, be advantageous to feed rations containing over 2 pounds of digestible protein a day, and of a nutritive ratio narrower than 1:6–7, to cows of average dairy capacity.

APPENDIX.

*Average production and food consumption of cows in University herd during winter periods, 1898–1904.**

Name of Cow.	Yield per Day.		Av. per cent fat.	Net Nutrients.			Net Nutr. per 100 Lbs. Milk			Net Nutr. per 1 Lb. Fat.			Days in milk.	Av. live weight.
	Milk.	Fat.		Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. carbh. and fat.		
Gold:	Lbs.	Lbs.		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs	Lbs.	Lbs.		Lbs.
1901-2......	22.4	1.43	6.38	16.6	1.45	10.67	74.1	6.47	47.6	11.6	1.01	7.46	182	806
Lady:														
1900-1......	24.7	1.03	4.17	14.1	1.14	8.46	57.1	4.62	34.3	13.7	1.11	8.21	176	1,067
1901-2......	27.6	1.15	4.17	12.8	1.24	7.57	46.4	4.49	27.4	11.1	1.08	6.58	182	1,212
1902-3.. ...	39.9	1.63	4.09	17.5	2.10	11.36	43.9	5.26	28.5	10.7	1.29	6.97	183	1,147
1903-4......	47.1	2.00	4.25	12.4	1.86	6.94	26.3	3.95	14.7	6.2	.93	3.47	142	1,169
Alma:														
1899-1900...	31.2	.95	3.04	15.6	1.93	10.38	50.0	6.19	33.3	16.5	2.03	10.90	182	887
1900-1......	34.6	1.11	3.21	15.2	1.36	9.77	43.9	3.93	28.2	13.7	1.23	8.80	182	967
1901-2......	45.4	1.41	3.11	17.8	1.83	11.15	39.2	4.03	24.6	12 6	1.30	7.91	182	1,103
1902-3......	45.6	1.41	3.09	13.2	1.51	8.50	29.0	3.31	18.6	9.4	1.07	6.03	151	1,001
1903-4......	53.6	1.66	3.09	8.5	1.47	5.12	15.8	2.74	9.6	5.1	.89	3.08	118	1,083
Murphy:														
1899-1900...	21.7	1.23	5.67	9.9	1.08	5.99	45.6	4.98	27.6	8.0	.88	4.87	171	855
1900-1......	22.8	1.21	5.31	15.2	1.22	9.35	66.7	5.35	41.0	12.6	1.01	7.73	175	868
Goodrich:														
1898-9	25.5	1.19	4.67	13.8	1.22	8.46	54.1	4.78	33.2	11.6	1.03	7.11	181	739
1899-1900.	25.6	1.23	4.80	13.9	1.53	8.72	54.3	5.98	34.1	11.3	1.24	7.09	182	778
Lizzie:														
1898-9.. .	22.4	1.17	5.22	11.8	1.10	7.34	52.7	4.91	32.8	10.1	.94	6.28	181	1,022
1899-1900....	25.3	1.24	4.90	8.8	.93	5.53	34.8	3.68	21.9	7.1	.75	4.46	177	955
Donation:														
1901-2......	31.3	1.10	3.52	11.5	1.10	6.63	36.6	3.50	21.1	10.5	1.00	6.03	160	1,187
1902-3......	36.5	1.31	3.59	7.9	1.05	5.26	21.6	2.88	14.4	6.0	.80	4.02	142	1,248
1903-4......	36.4	1.35	3.71	6.8	1.45	4.11	18.7	3.98	11.3	5.0	1.07	3.04	140	1,301
Maud:														
1898-9......	21.3	.92	4.32	11.1	1.03	6.53	52.1	4.84	30.7	12.1	1.12	7.10	181	1,131
1899-1900...	25.8	1.06	4.12	10.9	1.15	6.99	42.2	4.46	27.1	10.3	1.08	6.59	182	1,078
1900-1......	33.0	1.29	3.91	12.7	1.01	7.87	38.5	3.06	23.8	9.8	.78	6.10	148	1,061
1901-2......	36.4	1.36	3.74	14.9	1.41	9.73	40.9	3.88	26.7	11.0	1.04	7.15	165	1,109
1902-3.. .	37.6	1.36	3.62	9.0	1.15	5.19	23.9	3.06	13.8	6.6	.85	3.82	102	1,210
1903-4......	21.8	.95	4.34	10.5	1.39	6.15	47.9	6.35	28.1	11.1	1.46	6.47	181	1,188
McGeoch:														
1901-2......	33.5	1.32	3.94	11.6	1.57	7.08	34.6	4.69	21.1	7.8	1.19	5,36	147	1,186
1902-3......	28.2	1.04	3.69	6.9	.92	4.31	24.5	3.26	15.3	6.6	.89	4.14	147	1,203
1903-4......	13.7	.54	3.94	6.9	1.24	3.96	51.0	9.04	28.9	12.8	2.30	7.33	181	1,355
Nan:														
1898-9......	18.2	.98	5.39	16.1	1.31	9.83	88.5	7.20	54.0	16.4	1.34	10.00	181	712
1899-1900...	28.6	1.42	4.97	13.6	1.49	8.32	47.6	5.21	29.1	9.6	1.05	5.86	138	787
1900-1......	17.7	.89	5.03	11.7	.87	7.46	66.1	4.92	42.1	13.1	.98	8.38	182	780
1901-2......	32.2	1.44	4.47	15.0	1.38	9.06	46.6	4.29	28.2	10.4	.96	6.29	147	799

* Data for the winter period 1903-4 have been included in these tables.

Average production and food consumption of cows in University herd during winter periods, 1898–1904—Continued.

Name of Cow.	Yield Per Day.		Av. per cent fat.	Net Nutrients.			Net Nutr. per 100 Lbs. Milk.			Net Nutr. per 1 Lb. Fat.			Days in milk.	Av. live weight.
	Milk.	Fat.		Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. carbh. and fat.		
Bessie:	Lbs.	Lbs.		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.		Lbs.
1898-9.... .	22.9	1.11	4.85	12,6	1.21	7.67	55.0	5.28	33.5	11.4	1.09	6.91	181	832
1899-1900...	25.2	1.22	4.84	12.6	1.33	7.94	40.0	5.28	31.5	10.3	1.09	6.51	182	819
1900-1	25.3	1.14	4.51	11.1	1.08	7.01	43.9	4.27	27.7	9.7	.95	6.15	182	860
1901-2	24.3	1.17	4.81	12.9	1.17	7.75	53.1	4.81	31.9	11.0	1.00	6.62	182	923
1902-3......	26.1	1.18	4.52	11.0	1.48	6.74	42.1	5.67	25.8	9.3	1.25	5.71	183	873
1903-4	24.6	1.31	5.32	5.1	.61	2.56	20:7	2.48	10.4	3.9	.47	1.95	79	1,032
Joe:														
1901-2	28.9	.97	3.36	16.5	1.94	8.92	57.1	6.71	30.9	17.0	2.00	9.20	182	1,073
1902-3......	38.9	1.33	3.42	14.8	1.83	8.23	38.0	4.70	21.2	11.1	1.38	6.19	183	1,040
1903-4......	44.8	1.59	3.56	12.2	2.16	7.51	27.2	4.82	16.8	7.7	1.36	4.72	168	1,107
Dora:														
1898-9......	25.6	1.14	4.45	11.4	1.09	7.02	44.5	4.26	27.4	10.0	.96	6.16	181	950
1899-1900...	24.2	1.08	4.46	10.5	1.16	6.63	43.4	4.79	27.4	9.7	1.07	6.14	182	1,066
Chloe:														
1899-1900...	21.4	.81	1.79	9.7	1.09	7.43	45.3	5.09	34.7	12.0	1.35	9.17	182	1,188
1900-1	28.8	1.03	3.58	9.4	1.03	5.99	32.6	3.58	20.8	9.1	1.00	5.82	182	1,212
1901-2	42.2	1.43	3.39	12.4	2.51	9.42	29.4	5.95	22.3	8.7	1.76	6.59	182	1,354
Rose:														
1898-9	25.5	1.12	4.39	8.4	.87	5.18	32.9	3.41	20.3	7.5	.78	4.63	143	1,246
1899-1900 .	19.2	1.00	5.21	9.8	1.17	6.37	51.0	6.09	33.2	9.8	1.17	6.37	147	1,170
Duchess;														
1898-9......	24.3	.96	3.95	9.4	9.7	5.98	38.7	3.99	24.6	9.8	1.01	6.23	181	1,338
1899-1900...	26.0	1.21	4.65	12.2	1.45	8.17	46.9	5.58	31.4	10.1	1.20	6.75	182	1,236
1900-1......	19.9	.81	4.07	9.9	.89	6.60	49.7	4.47	33.2	12.2	1.10	8.15	172	1,289
Pauline:														
1898-9	10.3	.44	4.28	4.6	.78	4.21	44.7	7.57	40.9	10.5	1.77	9.57	181	1,333
1899-1900...	20.5	.84	4.10	5.2	.58	3.57	25.4	2.83	17.4	6.2	.70	4.25	182	1,270
1900-1.....	29.5	1.15	3.90	7.7	.89	6.32	26 1	3.06	21.4	6.7	.77	5.50	177	1,171
1901-2......	28.9	1.15	3.98	9.8	1.09	5.43	33.9	3.77	18.8	8.5	.95	4.72	171	1,314
1902-3......	35.6	1.36	3.82	6.4	.80	4.32	18.0	2.25	12.1	4.7	.59	3.18	136	1,344
Ella:														
1898-9......	17.1	.88	5.15	10.7	1.00	6.43	62.6	5.85	37.6	12.2	1.14	7.31	156	924
1899-1900...	21.6	1.14	5.28	5.9	.73	3.58	27.3	3.38	16.6	5.2	.64	3.14	133	1,049
1900-1......	17.2	.94	5.47	8.0	.74	4.96	46.5	4.30	28.8	8.5	.79	5.28	153	1,041
1901-2......	19.0	1.07	5.63	8.5	.75	5.19	44.7	3.95	27.3	8.0	.70	4.85	147	1,081
1902-3......	15.8	.82	5.19	5.6	.57	3.64	35.4	3.61	23.0	6.8	.70	4.44	156	1,038
Reba:														
1899-1900...	11.7	.67	5.73	10.8	1.01	6.76	92.4	8.63	57.8	16.2	1.51	10.10	156	733
1900-1......	24.6	1.15	4.67	8.9	.70	5.13	36.2	2.85	20.9	7.7	.61	4.46	107	842
1901-2	22.1	1.18	5.34	7 8	.67	4.77	35.3	3.03	21.6	6.6	.57	4.05	115	967
1902-3......	16.6	.84	5.06	5.6	.53	3.46	33.7	3.19	20.8	6.7	.63	4.12	133	912
1903-4......	15.1	.88	5.80	7.1	.92	4.24	47.0	6.09	28.1	8.1	1.05	4.82	136	969
Laura:														
1901-2......	16.0	.90	5.63	16.4	1.77	10.03	102.5	11.10	62.7	18.2	1.97	11.10	182	905
1902-3	18.3	.97	5.30	11.3	1.35	7.02	61.7	7.38	38.4	11.6	1.39	7.24	183	913
1903-4......	16.1	.83	5.16	11.1	1.49	6.06	69.0	9.25	37.6	13.4	1.80	7.30	181	955
Brownie:														
1901-2......	16.6	.92	5.54	13.8	1.17	8.36	83.1	7.05	50.4	15.0	1.27	9.09	182	1,030
1902-3......	18.4	.94	5.11	7.5	.88	4.72	40.8	4.78	25.7	8.0	.94	5.02	150	1,036
1903-4......	25.7	1.50	5.84	8.6	1.51	5.19	33.5	5.88	20.2	5.7	1.01	3.46	155	1,035

Average production and food consumption of cows in University herd during winter periods, 1898-1904—Continued.

Name of Cow.	Yield per Day.		Av. per cent fat.	Net Nutrient.			Net Nutr. per 100 Lbs. Milk.			Net Nutr. per 1 Lb. Fat.			Days in milk.	Av. live weight.
	Milk.	Fat.		Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. carbh. and fat.	Dry matter.	Dig. protein.	Dig. Carbh. and fat.		
	Lbs	Lbs.		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.		Lbs.
June:														
1901-2......	21.7	.80	3.69	17.7	1.82	11.14	81.6	8.39	51.3	22.1	2.27	13.9	182	966
1902-3......	26.2	.98	3.74	7.9	.82	4.84	30.2	3.13	18.5	8.1	.84	4.94	138	1,045
1903-4......	21.7	.83	3.81	8.6	1.35	5.09	39.6	6.22	23.5	10.4	1.63	6.13	147	1,259
Hill:														
1901-2......	20.9	.88	4.93	16.4	1.50	10.26	78.5	7.18	49.1	18.6	1.70	11.66	182	1,021
Dolly:														
1898-9......	6.3	.31	4.92	7.0	.70	4.40	111.0	11.10	69.8	22.6	2.26	14.2	181	1,137
1899-1900...	22.7	1.21	5.33	7.9	.82	5.16	34.8	3.61	22.7	6.5	.68	4.26	182	1,080
1900-1......	23.1	1.12	4.85	11.2	1.13	7.44	48.5	4.89	32.2	10.0	1.01	6.64	182	1,057
May:														
1898-9......	15.4	.87	5.65	7.9	.78	4.99	51.3	5.06	32.4	9.1	.90	5.74	152	945
Campbell:														
1899-1900..	26.5	1.05	3.96	7.6	.84	4.94	28.7	3.17	18.7	7.2	.70	4.71	154	1,098
1900-1......	26.4	.95	3.60	10.2	.91	6.32	38.6	3.45	24.0	10.7	.96	6.65	97	999
1901-2......	25.9	1.01	3.90	8.7	.89	5.37	33.6	3.44	20.7	8.6	.88	5.32	127	1,224
1902-3.....	10.6	.41	3.87	6.1	.74	3.98	57.5	6.98	37.5	14.9	1.80	9.15	111	1,225
1903-4......	14.5	.61	4.21	5.7	.80	3.48	39.3	5.52	24.0	9.4	1.31	5.70	181	1,211
Princess.														
1899-1900...	27.9	1.08	3.87	11.3	1.24	7.13	40.5	4.44	25.6	10.5	1.15	6.60	154	1,000
1900-1......	23.5	.91	3.87	8.8	.69	5.69	37.4	2.94	24.2	9.7	.76	6.25	155	1,092
1901-2......	17.9	.59	3.30	9.1	1.16	7.00	50.8	6.48	39.1	15.4	1.97	11.9	182	1,191
Dorine:														
1902-3......	15.2	.81	5.33	6.4	.75	3.85	42.1	4.93	25.3	7.9	.93	4.75	138	857
1903-4......	14.8	.88	5.98	6.2	.90	3.70	41.9	6.08	25.0	7.0	1.02	4.20	145	1,022
Muriel:														
1902-3......	12.6	.78	6.19	6.7	.77	4.04	53.2	6.11	32.1	8.6	.99	5.18	153	821
1903-4......	16.3	1.01	6.21	7.2	.65	4.26	44.2	3.99	26.1	7.1	.64	4.22	138	936
Hoard:														
1899-1900.	12.3	.75	6.10	12.7	1.31	7.96	103.0	10.7	64.7	16.9	1.75	10.6	148	788
1900-1......	12.8	.72	5.63	9.3	.88	5.89	72.7	6.88	46.0	12.7	1.21	8.19	171	800
1901-2......	15.2	.88	5.79	6.3	.75	3.87	41.4	4.93	25.5	7.2	.85	4.40	182	823
1902-3......	13.8	.73	5.29	8.5	1.33	4.36	61.6	9.64	31.6	11.6	1.82	5.97	183	813
Dixie:														
1902-3......	21.2	.76	3.58	9.3	.78	3.24	43.9	3.68	15.4	12.2	1.03	4.26	120	1,130
Molly:														
1902-3.. ...	20.1	.72	3.58	11.5	.92	5.27	57.2	4.58	26.2	16.0	1.28	7.32	183	1,213
Belle:														
1898-9......	18.4	.77	4.19	8.6	.97	5.19	46.7	5.27	28.2	11.2	1.26	6.74	181	1,220
1899-1900...	10.3	.49	4.76	4.4	.55	2.63	42.7	5.34	25.5	9.0	1.13	5.37	117	1,361
1900-1......	9.1	.44	4.84	1.4	.37	1.02	14.5	4.07	11.2	3.2	.84	2.32	107	1,335
1901-2......	18.6	.72	3.87	10.0	.97	6.40	53.8	5.22	34.4	13.9	1.35	8.89	173	1,393

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